THE CITY OF SAN DIEGO

Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant) 2009

City of San Diego
Ocean Monitoring Program

Public Utilities Department
Environmental Monitoring and Technical Services Division

THE CITY OF SAN DIEGO

June 30, 2010

Mr. David Gibson, Executive Officer
Regional Water Quality Control Board
San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Attention: POTW Compliance Unit

Dear Sir:

Enclosed is the 2009 Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, South Bay Water Reclamation Plant as required per NPDES Permit No. CA0109045, Order No. 2006-067. This report contains data summaries, analyses and interpretations of the various portions of the ocean monitoring program, including oceanographic conditions, water quality, sediment characteristics, macrobenthic communities, demersal fishes and megabenthic invertebrates, and bioaccumulation of contaminants in fish tissues. These data are also presented in the International Boundary and Water Commission's annual report for discharge from the International Wastewater Treatment Plant (NPDES Permit No. CA0108928, Order No. 96-50).

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, I certify that the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Sincerely,

Steve Meyer
Deputy Public Utilities Director

SM/tds

Enclosures: 1. Annual Receiving Waters Monitoring Report
2. CD containing PDF file of this report

cc: Department of Environmental Health, County of San Diego
U.S. Environmental Protection Agency, Region 9
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Annual Receiving Waters Monitoring Report

for the

South Bay Ocean Outfall

(South Bay Water Reclamation Plant)

2009

Prepared by:

City of San Diego
Ocean Monitoring Program
Public Utilities Department
Environmental Monitoring and Technical Services Division

June 2010

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Cover Photos

Representative crustaceans from the South Bay Ocean Outfall monitoring program, including (clockwise from top left): *Amphideutopus oculatus*, *Leptochelia dubia*, *Ampelisca brachycladus*, *Ampelisca cristata cristata*, *Diastylopsis tenuis*. Photos by Ricardo Martinez-Lara.

Acknowledgments

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Executive Summary

Executive Summary

The City of San Diego (City) conducts extensive ocean monitoring to evaluate potential environmental effects from the discharge of treated wastewater to the Pacific Ocean via the South Bay Ocean Outfall (SBOO). The data collected are used to determine compliance with receiving water conditions as specified in the National Pollution Discharge Elimination System (NPDES) permits for the City's South Bay Water Reclamation Plant (SBWRP) and the International Boundary and Water Commission's International Wastewater Treatment Plant (IWTP). Since treated effluent from the SBWRP and IWTP commingle before being discharged to the ocean through the SBOO, a single monitoring and reporting program approved by the San Diego Regional Water Quality Control Board and U.S. EPA is conducted to comply with both permits.

The primary objectives of the South Bay ocean monitoring program are to a) measure compliance with NPDES permit requirements and 2001 California Ocean Plan (COP) standards, and b) assess any impact of wastewater discharged through the outfall on the local marine environment, including effects on water quality, sediment conditions, and marine organisms. The study area centers around the SBOO discharge site, located approximately 5.6 km offshore at a depth of 27 m. Shoreline monitoring extends from Coronado (San Diego) southward to Playa Blanca in northern Baja California (Mexico), while regular offshore monitoring occurs in adjacent areas ranging from about 9 to 55 m in depth.

Prior to the initiation of discharge in 1999, the City conducted a 3½ year baseline study designed to characterize pre-discharge background conditions in the South Bay region. Additionally, a larger-scale regional survey of benthic conditions is typically conducted each year at sites ranging from northern San Diego County (around La Jolla−Del Mar) south to the U.S./Mexico international border. These surveys are useful for evaluating patterns and trends over larger geographic areas, thus providing additional information to help distinguish possible reference areas from sites impacted by anthropogenic influences. The results of the 2009 regional survey off San Diego are presented herein.

The receiving waters monitoring activities for the South Bay region are separated into several major components, which are organized into nine chapters in this report. Chapter 1 presents a general introduction and overview of the South Bay ocean monitoring program. In Chapter 2, data regarding various physical and chemical parameters are evaluated to characterize oceanographic conditions and water mass transport for the region. Chapter 3 presents the results of water quality monitoring conducted along the shore and in local coastal waters, including measurements of fecal indicator bacteria (FIB) to determine compliance with COP water contact standards. Assessments of benthic sediment quality and the status of soft-bottom macro-benthic invertebrate communities are presented in Chapters 4 and 5, respectively. Chapter 6 presents the results of trawling activities designed to monitor communities of demersal (bottom dwelling) fishes and megabenthic invertebrates. Bioaccumulation assessments to determine if contaminants are present in the tissues of local fishes captured via trawls or by hook and line are presented in Chapter 7. Results of the 2009 regional survey of sediment conditions and benthic macrofaunal communities are presented in Chapters 8 and 9, respectively. In addition to the above activities, the City and IBWC support other projects relevant to assessing the quality of ocean waters in the region. One such project involves aerial and satellite imaging studies of the San Diego/Tijuana coastal region. The results of the remote sensing efforts conducted during 2009 are incorporated herein into discussions of oceanographic and water quality conditions.

This report focuses on the results and conclusions of all ocean monitoring activities conducted in the South Bay region from January 2009 through

December 2009. An overview and summary of the main findings for each of the major components of the program are included below.

Oceanographic Conditions

The South Bay outfall region was characterized by relatively normal oceanographic conditions in 2009 that were typical of previous years. This included seasonal patterns such as localized upwelling with corresponding phytoplankton blooms in the spring, maximum stratification (layering) of the water column in mid-summer, and well-mixed waters (i.e., reduced stratification) during the winter. Although some differences in water temperatures, salinity, dissolved oxygen, and pH were observed close to the discharge site, it was also clear that any variation among stations was small and restricted to a highly localized area around the outfall. Aerial imagery results confirmed that the wastewater plume reached near-surface waters directly above the SBOO discharge site when the water column was well mixed during the first (January–March) and last (November–December) quarters of the year. In contrast, the plume remained deeply submerged between April–October when the water column was stratified. Overall, ocean conditions during the year were consistent with larger scale patterns that have been well documented for southern California or northern Baja California. These findings suggest that natural factors such as upwelling of deep ocean waters and widespread climatic events (e.g., El Niño, La Niña) continue to explain most of the temporal and spatial variability observed in water quality parameters for the South Bay region.

Water Quality

There was no evidence that contaminated waters associated with wastewater discharge via the SBOO reached the shore or near-shore recreational waters off southern San Diego in 2009. Although elevated levels of fecal indicator bacteria (FIB) were detected in seawater samples collected along or near the shore, this appeared mostly due to rainfall effects and not to shoreward transport of the wastefield. For example, about 95% of all elevated FIBs at the shore and kelp stations occurred during the wet season when rainfall was greatest. Additionally, analysis of bacterial distribution patterns and remote sensing observations indicated that outflows or turbidity plumes originating from the Tijuana River and Los Buenos Creek in northern Baja California were the likely sources of contamination during these times. This general relationship between rainfall and bacterial levels has remained consistent since monitoring began in 1995. Finally, most of the elevated FIB densities reported in 2009 that were not associated with higher rainfall occurred at a few sites located within 1000 m of the outfall diffuser legs and at depths of 18 m or below.

Overall compliance with the 2001 COP water contact standards was similar to that in 2008. For example, compliance ranged from 56 to 100% for the various COP standards at the eight shore stations located north of the U.S./Mexico border, and from 80 to 100% at the three near-shore kelp stations. Differences in compliance rates during the year generally reflected trends in elevated bacterial levels, with compliance being the lowest between the months of January–March and in December when rainfall was greatest.

Sediment Conditions

The composition of benthic sediments sampled at the regular South Bay stations in 2009 varied from fine silts to very coarse sands or other relatively large particles (e.g., gravel, shells), which was similar to patterns seen in previous years. Overall, the large variation in particle sizes may be partially attributed to the different geological origins of several unique sediment types, including red relict sands, other coarse sands, shell hash, and detrital materials. In addition, the transport and deposition of sediments originating from sources such as the Tijuana River and San Diego Bay, may contribute to higher silt content at various sites. However, there was no evident relationship between sediment composition and proximity to the SBOO during the year.

Overall, sediment quality at the SBOO monitoring sites was similar in 2009 to previous years, and there was no evidence of contaminant accumulation that could be attributed to wastewater discharge. Concentrations of the various trace metals, organic loading indicators, pesticides (e.g., DDT), and PCBs were highly variable in local sediments. Most sediment samples had contaminant levels that were similar to those detected prior to wastewater discharge, although a few did exceed pre-discharge maximums. Additionally, concentrations of most parameters remained relatively low compared to other coastal areas of southern California. The potential for degradation by any of the detected chemical contaminants was further evaluated by using the effects-range low (ERL) and effects-range median (ERM) sediment quality guidelines as benchmarks. Only DDT, arsenic, copper and nickel ever exceeded their ERLs, none of which did so in more than three samples; the ERM was not exceeded for any contaminant. The stations with sediment samples that had contaminant levels above pre-discharge values or that exceeded their ERL were widely distributed, and there were no patterns that could be attributed to a point source or wastewater discharge. Instead, concentrations of total organic carbon, total nitrogen, sulfides, several metals, and DDT tended to be higher at sites characterized by finer sediments. This pattern is consistent with results from other studies in which the accumulation of fine particles has been shown to greatly influence the organic and metal content of sediments.

Macrobenthic Communities

Benthic macrofaunal assemblages surrounding the SBOO were similar in 2009 to those that occurred during previous years, and varied mostly along gradients of sediment composition (e.g., percent sand, silt and clay) and depth. These assemblages were typical of those occurring in other sandy, shallow- and mid-water habitats throughout the Southern California Bight (SCB). For example, most of the sandier, shallower sites contained high abundances of the spionid polychaete *Spiophanes norrisi* (formerly=*S. bombyx*), a species characteristic of similar habitats and assemblages in the SCB. In contrast, slightly different assemblages occurred at mid-depth stations that had finer sediments characteristic of much of the southern California mainland shelf. Finally, sites with sediments composed of significant quantities of coarse sands or shell hash were inhabited by a unique assemblage characterized by several species of polychaetes (i.e., *Polycirrus* sp, *Protodorvillea gracilis*, *Hesionura coineaui difficilis*, *Micropodarke dubia*, *Typosyllis* sp SD1, and *Pisione* sp).

Benthic community structure parameters such as species richness and total abundance also varied with depth and sediment type during the year, with no clear patterns relative to the SBOO discharge area. Instead, region-wide fluctuations in total macrofaunal abundance still appear to mirror historical patterns for *Spiophanes norrisi*. The range of values for most parameters was similar in 2009 to that seen in previous years, and results for the benthic response index (BRI) were generally characteristic of reference conditions for the SCB. In addition, changes that did occur in macrobenthic community structure during the year were similar in magnitude to those that have occurred previously and elsewhere off southern California. Such changes often correspond to large-scale oceanographic processes or other natural events. Overall, macrofaunal assemblages in the South Bay region remain similar to those observed prior to wastewater discharge and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf. There was no evidence that wastewater discharge has caused degradation of the marine benthos in the SBOO monitoring region.

Demersal Fishes and Megabenthic Invertebrates

Speckled sanddabs continued to dominate fish assemblages surrounding the SBOO in 2009 as they have in previous years. This species occurred at all stations and accounted for 38% of the total catch for the year. California lizardfish and yellowchin sculpin were also common, together accounting for about another 44% of all fishes collected. Other characteristic, but less abundant species in the South Bay region include roughback sculpin, longfin sanddab, hornyhead turbot, California tonguefish, and plainfin midshipman. Although the specific composition and structure of fish assemblages varied among stations in 2009, most differences reflected the large variations in speckled sanddab, California lizardfish, and yellowchin sculpin populations.

Assemblages of the relatively large (megabenthic) surface-dwelling macroinvertebrates captured by trawls in the region were also dominated by a single prominent species, the sea star *Astropecten verrilli*. Consequently, variations in megabenthic community structure in the South Bay generally reflect changes in the abundance of this sea star, as well as other common species such as the brittle stars *Ophiothrix spiculata* and *O. luetkeni*, and the sand dollar *Dendraster terminalis*.

Overall, the 2009 trawl survey results indicate that trawl-caught fish and invertebrate communities in the region are unaffected by wastewater discharge. The relatively low species richness and small populations present are consistent with the shallow, sandy habitat in which the trawl stations are located. Further, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, suggesting a lack of significant anthropogenic influence. Instead, changes in these communities appear to be more likely due to natural factors such as seasonal water temperature fluctuations or large-scale oceanographic events (e.g., El Niño), as well as the mobile nature of many species.

The types and frequencies of external health problems for fish can be important indicators of environmental impact. Examinations of trawl-caught fish for evidence of disease (e.g., tumors, fin erosion, skin lesions) or the presence of ectoparasites showed that local fish populations remain generally healthy. For example, external parasites and other external abnormalities occurred in less than 0.1% of the fish collected in the South Bay region during 2009. Overall, these results were consistent with the findings from previous years and provided no indication of any outfall effect.

Contaminants in Fish Tissues

The accumulation of contaminants in marine fishes can occur due to several factors, including direct exposure to contaminated water or sediments, and to the ingestion of contaminated prey. Consequently, the bioaccumulation of various contaminants in local fishes was assessed by analyzing liver tissues from trawl-caught fishes and muscle tissues from fishes captured by hook and line. There was no clear evidence to suggest that contaminant loads in the tissues of fishes captured in the SBOO region were affected by wastewater discharge in 2009. Although several fish tissue samples contained metals that exceeded pre-discharge maximums, concentrations of most contaminants were generally similar to that observed prior to discharge. In addition, the samples that did exceed pre-discharge levels occurred at widely distributed stations and showed no pattern relative to the SBOO discharge site. Furthermore, all contaminant values were within the range of values reported previously for southern California fishes.

The occurrence of both metals and chlorinated hydrocarbons in the tissues of South Bay fishes may be due to many factors, including the ubiquitous distribution of many contaminants in coastal sediments off southern California. Other factors that affect the bioaccumulation and distribution of contaminants in local fishes include the different physiologies and life history traits of various species. Exposure to contaminants can vary greatly between species and even among individuals of the same species depending on migration habits. For example, fish may be exposed to pollutants in a highly contaminated area and then move into a region that is less contaminated. This is of particular concern for fishes collected in the vicinity of the SBOO, as there are many other point and non-point sources in the region that may contribute to contamination.

San Diego Regional Survey

The summer 2009 San Diego regional benthic survey covered an area ranging from offshore of La Jolla south to the U.S./Mexico border. A total of 40 sites were sampled at depths ranging from 11 m to 413 m. These included 34 stations originally sampled in 1999 at continental shelf depths (i.e., 0–200 m), and six new stations located in deeper waters along the upper continental slope (i.e., 200–500 m). These latter samples were added to augment the regional program to include information on deeper benthic habitats off San Diego.

Regional Sediments

Particles size distribution in sediments at the regional stations was similar to that seen in previous years, with only five sites showing any substantial change between 1999 and 2009. As in the past, there was a trend towards coarser sediments (e.g., higher sand content) at the shallow near-shore areas compared to finer sands and/or silt at the deeper shelf sites. For example, sediments from stations along the inner shelf at depths less than 30 m were composed of about 89% sands and 8% fines (silt and clay), whereas sediments at the mid-shelf (30–120 m) and outer shelf (120–200 m) stations had finer sediments of 41% and 38% fines, respectively. The six stations located along the upper slope depths greater than 200 m contained the finest sediments, averaging about 69% fines and 31% sands. Correlation analysis confirmed that the proportion of fine sediments tended to increase with depth. Exceptions to this general pattern occurred in mid-shelf sediments offshore of the SBOO, as well as at several outer shelf sites along the Coronado Bank southwest of Point Loma. Sediment composition at the stations in these areas tended to be coarser with less fine materials than similar depth sites located off of Point Loma and further to the north. Overall, benthic sediments throughout the San Diego region reflect the diverse and patchy types of habitats that are common to the Southern California Bight (SCB).

Patterns in sediment chemistry levels at the 2009 survey sites were typical for the San Diego coastal region, and generally followed the expected relationship of increasing concentrations with decreasing particle size. For example, concentrations of the various organic loading indicators, metals, and other contaminants were generally higher along the outer-shelf and upper slope where the percentage of fines was typically greatest. Furthermore, these results did not show any pattern of contamination relative to wastewater discharge in either the South Bay or Point Loma regions or to any other point source.

Regional Macrofauna

The general distribution and types of macrobenthic assemblages along the San Diego shelf have shown little net change since the regional surveys began. For example, sites sampled in 2009 were remarkably similar to the same sites sampled in 1999 based on multivariate analyses and comparisons of differences in several important measures of benthic community structure (e.g., species richness, total abundance, diversity).

Results of the 2009 survey showed that benthic assemblages off San Diego segregated primarily by habitat characteristics such as depth and sediment grain size. These assemblages were also similar to those sampled in the past except for along the upper slope, which was first sampled this year. About one-third of the San Diego benthos was characterized by a mid-shelf, mixed sediment assemblage dominated by the brittle star *Amphiodia urtica.* This assemblage corresponds to the A*mphiodia* "mega-community" described previously for the SCB and that is common in the Point Loma region of San Diego. Several distinct near-shore assemblages were also present that were generally similar to those found in shallow, sandy sediment habitats throughout the SCB. These inner to shallow mid-shelf assemblages occurred in coarse sediments at depths between 11–43 m, and were dominated by polychaete worms such as *Owenia collaris, Spiophanes norrisi, Spio maculata,* and *Lumbrinerides platypygos*. Two different assemblages were present along the outer shelf to upper slope at depths between 122−257 m. One assemblage, characterized by the brittle star *Amphiodia digitata* and two cirratulid polychaetes, occurred in coarse sediments along the Coronado Bank. The second outer shelf assemblage occurred in mixed fine sediments, and was characterized by the bivalves *Tellina carpenteri*, *Adontorhina cylcia*, and *Axinopsida serricata*. The upper slope represented a unique habitat for the region, which was characterized by the finest sediments sampled during the 2009 survey (e.g., ~70% silt and clay). The assemblage characteristic of these upper slope sites was distinguished by fewer species and lower abundances than along the continental shelf, and was dominated mostly by molluscs such as the bivalves *Nuculana conceptionis* and *Ennucula tenuis*, and the scaphopod *Gadila tolmiei*.

There was no evidence of disturbance during the regional survey that could be attributed to wastewater discharges, disposal sites or other point sources. Overall, the San Diego benthos was in good condition during 2009, with 94% of the sites surveyed being classified in reference condition and 6% deviating only marginally based on assessments using the benthic response index (BRI). This pattern is consistent with recent findings for the entire SCB mainland shelf.

Conclusions

The findings and conclusions for the 2009 ocean monitoring effort for the South Bay outfall region, as well as the 2009 regional benthic survey, were consistent with previous years. Overall, there were limited impacts to local receiving waters, benthic sediments, and marine invertebrate and fish communities. There was no evidence that the SBOO wastefield reached near-shore recreational waters during the year. Although elevated bacterial levels did occur in near-shore areas, such instances were largely associated with higher rainfall during the wet season and not to shoreward transport of the wastewater plume. There were also no outfall related patterns in sediment contaminant distributions, or in differences between the various macrobenthic invertebrate and fish assemblages. The general lack of disease symptoms in local fish populations, as well as the low level of contaminants detected in fish tissues, was also indicative of a healthy marine environment. Finally, results of regional benthic survey conducted during the summer of 2009 also revealed no outfall related effects, and that benthic habitats in the region remain in good condition similar to much of the Southern California Bight mainland shelf.

Chapter 1
General Introduction

Chapter 1. General Introduction

INTRODUCTION

The South Bay Ocean Outfall discharges treated effluent to the Pacific Ocean that originates from two separate sources, including the International Wastewater Treatment Plant (IWTP) operated by the International Boundary and Water Commission (IBWC), and the City of San Diego's South Bay Water Reclamation Plant (SBWRP). Wastewater discharge from the IWTP began on January 13, 1999 and is performed under the terms and conditions set forth in Order No. 96–50, Cease and Desist Order No. 96–52 for NPDES Permit No. CA0108928. Discharge from the SBWRP began on May 6, 2002 and is currently performed according to the provisions set forth in Order No. R9-2006-0067 for NPDES Permit No. CA0109045. The Monitoring and Reporting Program (MRP) included in each of the above permits and orders defines the requirements for monitoring receiving waters in the South Bay coastal region, including sampling designs, compliance criteria, types of laboratory analyses, and data analysis and reporting guidelines.

All receiving waters monitoring for the South Bay outfall region with respect to the above MRPs has been performed by the City of San Diego since wastewater discharge began in 1999. The City also conducted 3½ years of pre-discharge monitoring in order to characterize background environmental conditions for the region (City of San Diego 2000a). The results of this baseline study provide background information against which post-discharge data and conditions may be compared. In addition, the City has conducted annual region-wide surveys off the coast of San Diego since 1994 either as part of regular South Bay monitoring requirements (e.g., City of San Diego 1998, 1999, 2000b, 2001–2003, 2006–2008) or as part of larger, multi-agency surveys of the entire Southern California Bight (e.g., Bergen et al. 1998, 2001; Noblet et al. 2002, Ranasinghe et al. 2003, 2007; Schiff et al. 2006). Such large-scale surveys are useful in characterizing the ecological health of diverse coastal areas and may help to identify and distinguish reference sites from those impacted by wastewater or stormwater discharges, urban runoff, or other sources of contamination.

Finally, the City and IBWC also contract with Ocean Imaging of Solana Beach, California to conduct a remote sensing program for the San Diego/Tijuana region as part of the ocean monitoring programs for the Point Loma and South Bay outfall areas. Imagery from satellite data and aerial sensors produce a synoptic picture of surface water clarity that is not possible using shipboard sampling alone. However, a major limitation of aerial and satellite images is that they only provide information about surface or near-surface waters (~0–15 m) without providing direct data regarding the movement, color, or clarity of deeper waters. In spite of these limitations, one objective of this project is to ascertain relationships between the various types of imagery and data collected in the field. With public health issues being a paramount concern of ocean monitoring programs, any information that helps to provide a clearer and more complete picture of water conditions is beneficial to the general public as well as to program managers and researchers. Having access to a large-scale overview of surface waters within a few hours of image collection also has the potential to bring the monitoring program closer to real-time diagnoses of possible contamination, and adds predictability to the impact that natural events such as storms and heavy rains may have on shoreline water quality. Results from the remote sensing program for calendar year 2009 are summarized in Svejkovsky (2010).

This report presents the results of all receiving waters monitoring activities conducted as part of the South Bay ocean monitoring program in 2009. Included are results from all fixed stations that comprise a grid surrounding the South Bay outfall, as well as results from the summer 2009 regional benthic survey of randomly selected sites off San Diego. The results of the remote sensing surveys conducted during the year as reported by Svejkovsky (2010) are also considered and integrated into interpretations of oceanographic and water quality data (e.g., fecal indicator bacteria, total suspended solids, oil and grease). Comparisons are also made herein to conditions present during previous years in order to evaluate changes that may be related to wastewater discharge and transport or to other anthropogenic or natural factors. The major components of the monitoring program are covered in the following chapters: Oceanographic Conditions, Water Quality, Sediment Characteristics, Macrobenthic Communities, Demersal Fishes and Megabenthic Invertebrates, Bioaccumulation of Contaminants in Fish Tissues, Regional Sediment Conditions, and Regional Macrobenthic Communities. Some general background information and procedures for the regular fixed-grid monitoring and regional surveys and associated sampling designs are given below and in subsequent chapters and appendices.

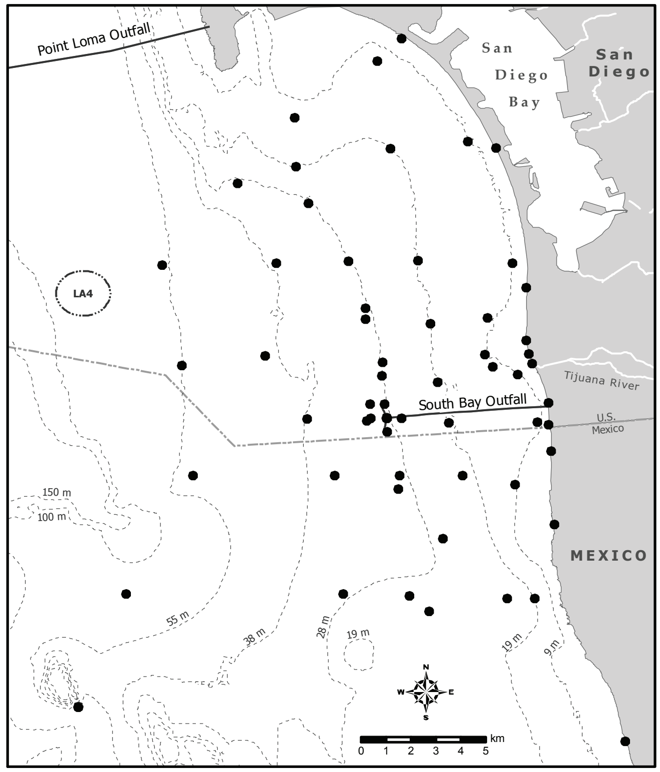

Figure 1.1
Receiving waters monitoring stations for the South Bay Ocean Outfall Monitoring Program.

Regular Fixed-Grid Monitoring

The South Bay Ocean Outfall is located just north of the border between the United States and Mexico. The outfall terminates approximately 5.6 km offshore at a depth of about 27 m. Unlike other southern California ocean outfall structures that are located on the surface of the seabed, the pipeline first begins as a tunnel on land and then continues under the seabed to a distance of about 4.3 km offshore. From there it connects to a vertical riser assembly that conveys effluent to a pipeline buried just beneath the surface of the seabed. This subsurface pipeline then splits into a Y-shaped multiport diffuser system, with the two diffuser legs extending an additional 0.6 km to the north and south. The outfall was originally designed to discharge effluent via a total of 165 diffuser ports and risers, which included one riser located at the center of the “Y” and 82 others spaced along each diffuser leg. However, consistent low flows have required closure of all ports along the northern diffuser leg and many along the southern diffuser as well since discharge began in order to maintain sufficient back pressure within the drop shaft so that the outfall can operate in accordance with the theoretical model. Consequently, wastewater discharge has been generally limited to the distal end of the southern diffuser leg, with the exception of a few intermediate points at or near the center of the diffuser legs.

The regular sampling area for the South Bay outfall region extends from the tip of Point Loma southward to Playa Blanca, northern Baja California (Mexico), and from the shoreline seaward to a depth of about 61 m (Figure 1.1). The offshore monitoring stations are arranged in a grid that spans the terminus of the outfall, with each site being monitored in accordance with NPDES permit requirements. Sampling at these fixed (core) stations includes monthly seawater measurements of physical, chemical, and bacteriological parameters in order to document water quality conditions in the area. Benthic sediment samples are collected semiannually to monitor macrobenthic invertebrate communities and sediment conditions. Trawl surveys are performed quarterly to monitor communities of demersal fish and large, bottom-dwelling invertebrates (megabenthos). Additionally, analyses of fish tissues are performed semiannually to assess the bioaccumulation of chemical constituents that may have ecological or human health implications.

Random Sample Regional Surveys

In addition to the core fixed-station sampling, the City typically conducts a summer benthic survey of sites distributed throughout the entire San Diego region as part of the monitoring requirements for the South Bay program. These surveys are based on an array of stations that are randomly selected by the United States Environmental Protection Agency (U.S. EPA) using the probability-based EMAP design. Surveys conducted in 1994, 1998, 2003, and 2008 involved other major southern California dischargers, were broader in scope, and included sampling sites representing the entire Southern California Bight (SCB) from Cabo Colonet, Mexico to Point Conception, USA. These surveys included the Southern California Bight Pilot Project (SCBPP) in 1994, and the 1998, 2003 and 2008 SCB Regional Monitoring Programs (i.e., Bight'98, Bight'03, and Bight'08, respectively). Results of the 1994–2003 regional programs are available in Bergen et al. (1998, 2001), Noblet et al. (2002), Ranasinghe et al. (2003, 2007), and Schiff et al. (2006), whereas analysis of data for Bight'08 is currently underway. A separate regional survey for San Diego was not conducted in 2004 in order to conduct a special "sediment mapping" study pursuant to an agreement with the San Diego Regional Water Quality Control Board (RWQCB) and U.S. EPA (see Stebbins et al. 2004, City of San Diego 2005).

The same randomized sampling design was used to select 40 new stations per year for each of the summer surveys restricted to the San Diego region in 1995–1997 and 1999–2002. Beginning in 2005, however, an agreement was reached between the City, RWQCB and EPA to revisit the same sites successfully sampled 10 years earlier in order to facilitate comparisons of long-term changes in benthic conditions. Unsuccessful sampling during all of these surveys was typically due to the presence of rocky substrates that made it impossible to collect benthic grab samples. Thus, 36 sites were revisited in 2005, 34 sites in 2006, and 39 sites in 2007. As indicated above, no separate survey for the San Diego region was conducted in 2008 due to participation in Bight'08. The summer 2009 regional survey covered an area ranging from La Jolla in northern San Diego County south to the U.S./Mexico border, and extending offshore from depths of about 11 m to 413 m (Figure 1.2). This included revisiting the 34 continental shelf stations sampled successfully in 1999, as well as 6 new stations located in waters deeper than 200 m. These latter upper slope stations were added to provide information on deeper benthic habitats off San Diego.

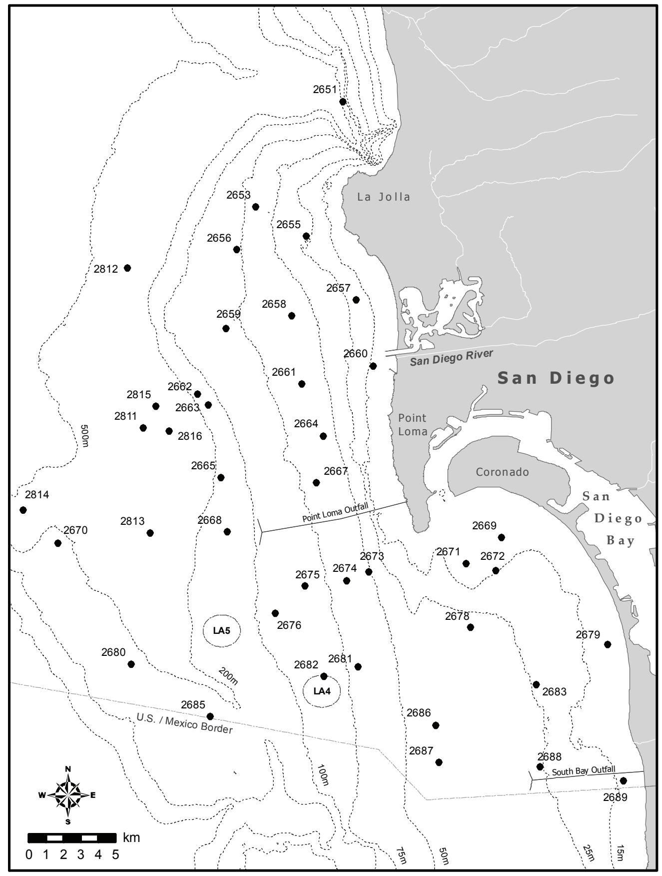

Figure 1.2
Regional benthic survey stations for the South Bay Ocean Outfall Monitoring Program.

Literature Cited

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and

R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

City of San Diego. (1998). San Diego Regional Monitoring Report for 1994–1996. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000a). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (1999). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2001). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2000). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2002). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2001). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (2002). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2002). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Stebbins, T.D., K.C. Schiff, and K. Ritter. (2004). San Diego Sediment Mapping Study: Workplan for Generating Scientifically Defensible Maps of Sediment Conditions in the San Diego Region. City of San Diego, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, and Southern California Coastal Water Research Project.

Svejkovsky J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2009 – 31 December, 2009. Ocean Imaging, Solana Beach, CA.

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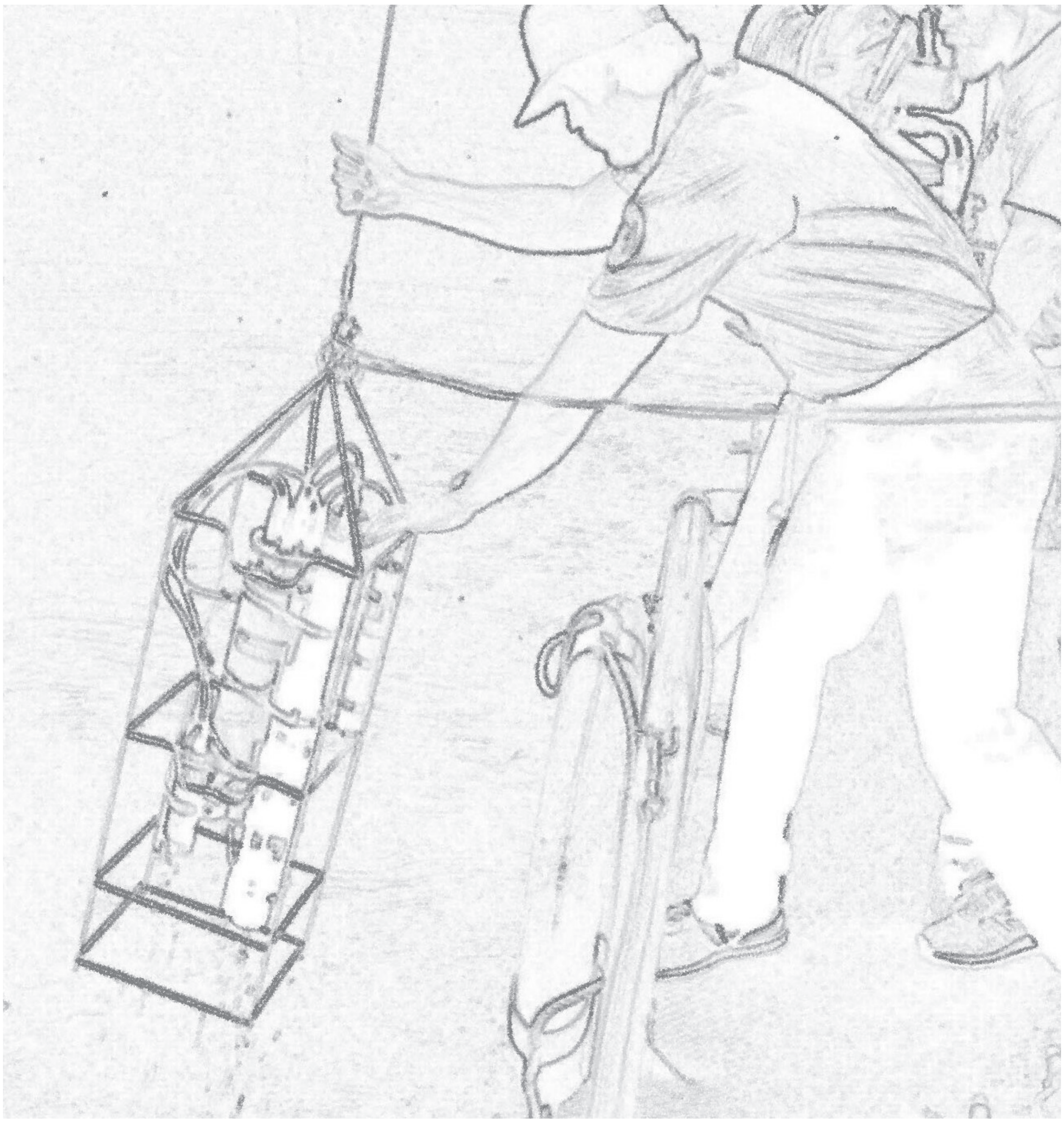
Chapter 2
Oceanographic Conditions



Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the South Bay Ocean Outfall (SBOO) to assist in evaluating possible impacts of wastewater discharge on the marine environment. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen and pH, in conjunction with biological indicators such as chlorophyll concentrations, are important indicators of biological and physical oceanographic processes (Skirrow 1975) that can impact marine life within a region (Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and the rate of discharge, but also by oceanographic factors that govern water mass movement (e.g., horizontal and vertical mixing of the water column, current patterns), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping.

In relatively nearshore waters such as the SBOO monitoring region, oceanographic conditions are strongly influenced by seasonal changes (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Southern California weather can generally be classified into a wet, winter season (typically December through February) and a dry, summer season (typically July through September) (NOAA/NWS 2010), and differences between these seasons affect oceanographic conditions such as water column stratification and current patterns. For example, storm activity during southern California winters brings higher winds, rain, and waves which often contribute to the formation of a well-mixed, relatively homogenous or non-stratified water column (Jackson 1986). The chance that wastewater plumes from sources such as the SBOO may surface is highest during such times when the water column is well mixed and there is little, if any, stratification. These conditions often extend into spring as the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the increasing elevation of the sun and longer days begin to warm surface waters resulting in increased surface evaporation (Jackson 1986). Mixing conditions also diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes like the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment, contaminant) plumes. In the South Bay outfall region these include plumes associated with tidal exchange from San Diego Bay, outflows from the Tijuana River in U.S. waters and Los Buenos Creek in northern Baja California, storm water discharges, and runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions both individually and synergistically.

This chapter describes the oceanographic conditions that occurred in the South Bay region during 2009. The main objectives are to: (1) describe deviations from expected oceanographic patterns, (2) assess possible influence of the SBOO wastewater discharge relative to other input sources, (3) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations. The results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejkovsky 2010). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site. The results reported herein are also referred to in subsequent chapters to explain patterns of indicator bacteria distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Field Sampling

Oceanographic measurements were collected at fixed sampling sites located in a grid pattern encompassing an area of ~450 km^2 surrounding the SBOO (Figure 2.1). These forty offshore stations (designated I1–I40) are located between 3.4–14.6 km offshore along or adjacent to the 9, 19, 28, 38 and 55-m depth contours. The stations were sampled monthly, usually over a 3-day period. This included 11 stations sampled on the day designated "North WQ" (stations I28–I38), 15 stations sampled on the day designated "Mid WQ" (stations I12, I14–I19, I22–I27, I39, I40), and 14 stations sampled on the day designated "South WQ" (stations I1–I11, I13, I20, I21). See Appendix A.1 for the actual dates samples were collected during 2009.

Data for the various oceanographic parameters were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), and dissolved oxygen (DO). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data reduction ensured that physical measurements used in subsequent analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the SBOO region during 2009 also included aerial and satellite image analysis performed by Ocean Imaging of Solana Beach, CA (see Svejkovsky 2010). All usable images for the study area captured during the year by the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite were downloaded from Ocean Imaging's website (Ocean Imaging 2010) for each month, as well as 19 high clarity Landsat Thematic Mapper (TM) images. High resolution aerial images

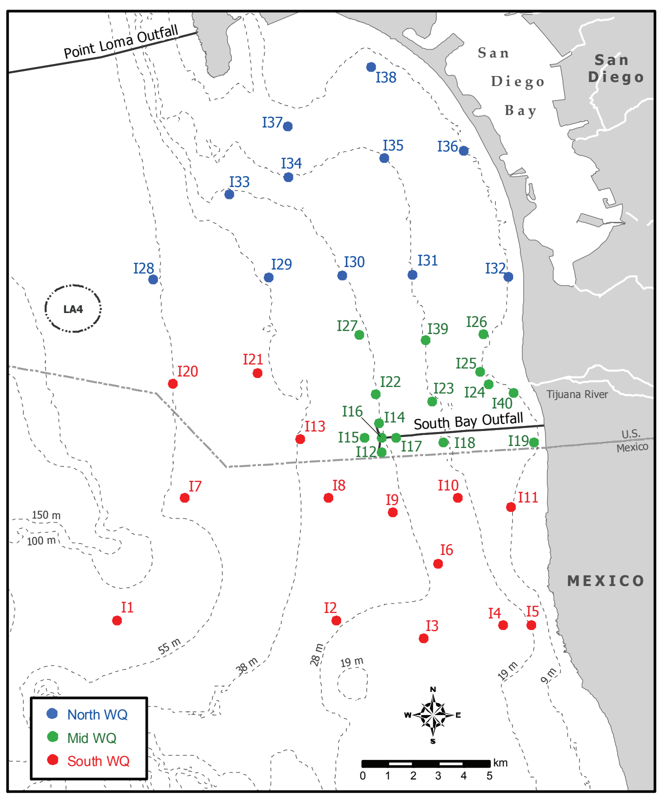


Figure 2.1
Water quality monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

were collected using Ocean Imaging's DMSC-MKII digital multispectral sensor and from a Jenoptik thermal imager integrated into the system. The DMSC's four channels were configured to a specific wavelength (color) combination designed to maximize detection of the SBOO wastewater signature by differentiating between the wastefield and coastal turbidity plumes. Depth of penetration for this sensor varies between 7–15 m depending on water clarity. The spatial resolution of the data is dependent upon aircraft altitude, but is typically maintained at 2 m. Fifteen DMSC overflights were conducted in 2009, which consisted of one to three flights per month during winter when the plume surfacing potential was greatest and when rainfall was typically highest. In contrast, only three surveys were flown during the spring and late summer months.

Data Treatment

The various water column parameters measured in 2009 were summarized as monthly means over all stations located along each of the 9, 19, 28, 38 and 55-m depth contours to provide an overview of trends throughout the entire year. For spatial analysis, 3-dimensional graphical views were created using Interactive Geographical Ocean Data System software (IGODS), which uses a linear interpolation between stations and with depth at each site. Data for these analyses were limited to four monthly surveys representative of the winter (February), spring (May), summer (August), and fall (November) seasons. These surveys were selected because they correspond to the quarterly water quality surveys conducted as part of the Point Loma Ocean Outfall monitoring program and the Central Bight Regional monitoring program. Additional spatial analysis included vertical profiles using the 1-m binned data for each parameter from the same surveys listed above, but limited to station I12 located closest to the wye's southern end, station I22 located just north of the outfall, and station I9 located just south of the outfall. These profiles were created to provide a more detailed view of data depicted in the IGODS graphics. Finally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events in the region. Anomalies were calculated by subtracting the monthly means for each year between 1995–2009 from the mean of all 15 years combined. Means were calculated using data for the three stations described above, with all depths combined.

Results and Discussion

Oceanographic Conditions in 2009

Water Temperature

In 2009, mean surface temperatures across the entire SBOO region ranged from 13.5°C in March to 21.3°C in September, while bottom temperatures averaged from 10.4°C in May to 16.8°C in October (Table 2.1). Water temperatures varied as expected by depth, with the lowest temperatures of the year occurring at the bottom during the spring (Figure 2.2, Figure 2.3). Temperatures also varied as expected by season, with the water column ranging from well-mixed in the winter, to highly stratified in summer, to weakly stratified in fall. Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures were important to limiting the surfacing potential of the wastewater plume during certain times of the year. Results from remote sensing observations and discrete bacteriological samples indicated that the plume surfaced during the winter when the water column was well-mixed, but was never detected in surface waters during the summer when the water column was highly stratified (e.g., Figure 2.4).

Ocean conditions were fairly consistent throughout the region during each season with two possible exceptions. First, slightly warmer surface waters occurred at the north end of the station grid in May (Figure 2.2B), possibly because these stations were sampled four days after those in the middle of the survey area and conditions changed during that short amount of time. Second, slightly different conditions were present in the water column near the outfall during February, May, and August (Figure 2.3). During these months, the water

Table 2.1

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the SBOO region during 2009. Values are expressed as means for each month pooled over all stations along each depth contour.

Depth Contour		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)													
9-m	Surface	13.9	14.5	13.5	16.4	17.5	17.1	16.1	19.7	19.3	17.6	16.0	15.0
	Bottom	13.7	14.1	12.1	14.9	16.5	13.0	13.0	14.0	15.4	16.8	14.9	15.0
19-m	Surface	13.9	14.5	13.6	16.1	17.3	16.9	16.5	19.8	19.5	17.3	16.0	15.3
	Bottom	13.6	13.5	11.5	11.9	13.6	11.9	11.8	12.4	13.9	15.4	14.4	14.9
28-m	Surface	14.0	14.4	14.0	15.9	17.4	17.0	15.9	18.9	19.8	17.1	16.0	15.3
	Bottom	13.3	12.9	11.2	11.4	11.9	11.5	11.5	12.1	13.1	14.6	14.0	14.5
38-m	Surface	14.5	14.5	14.3	16.2	17.6	17.8	18.0	19.0	20.5	17.8	16.2	15.5
	Bottom	12.7	12.4	10.9	11.1	10.9	11.4	11.4	11.5	12.6	14.1	13.2	14.5
55-m	Surface	14.3	14.5	14.2	16.0	17.4	17.8	18.6	18.5	21.3	18.2	16.2	15.6
	Bottom	12.0	11.7	10.8	10.6	10.4	11.0	11.0	11.0	11.8	13.1	12.7	13.0
Salinity (ppt)													
9-m	Surface	33.30	33.42	33.40	33.53	33.62	33.69	33.48	33.49	33.41	33.32	33.45	33.44
	Bottom	33.34	33.44	33.53	33.55	33.65	33.68	33.52	33.40	33.34	33.31	33.27	33.34
19-m	Surface	33.33	33.44	33.42	33.52	33.60	33.66	33.46	33.45	33.44	33.29	33.32	33.49
	Bottom	33.38	33.44	33.62	33.59	33.69	33.69	33.51	33.34	33.30	33.26	33.26	33.37
28-m	Surface	33.35	33.43	33.38	33.50	33.61	33.59	33.44	33.47	33.49	33.30	33.32	33.42
	Bottom	33.43	33.45	33.70	33.61	33.73	33.69	33.53	33.34	33.28	33.23	33.26	33.35
38-m	Surface	33.38	33.43	33.35	33.49	33.59	33.57	33.51	33.47	33.54	33.36	33.48	33.47
	Bottom	33.49	33.47	33.76	33.64	33.75	33.67	33.54	33.42	33.29	33.20	33.27	33.35
55-m	Surface	33.37	33.43	33.33	33.48	33.57	33.54	33.53	33.48	33.56	33.42	33.41	33.49
	Bottom	33.57	33.58	33.76	33.75	33.81	33.65	33.60	33.53	33.39	33.24	33.30	33.32
Dissolved Oxygen (mg/L)													
9-m	Surface	8.2	8.5	7.3	8.0	8.4	8.4	8.6	7.8	7.9	7.5	7.6	7.3
	Bottom	7.9	7.7	5.3	7.1	8.2	6.4	7.1	7.5	7.8	7.3	6.8	7.0
19-m	Surface	8.2	8.4	7.5	8.2	8.5	8.5	9.0	8.3	7.6	7.6	7.8	7.2
	Bottom	7.1	6.3	4.3	4.4	6.4	5.1	5.9	6.5	7.5	7.4	7.2	6.9
28-m	Surface	8.3	8.5	7.9	8.1	8.3	7.9	8.7	8.1	7.2	7.5	7.9	7.2
	Bottom	6.6	5.8	4.0	4.4	5.2	4.7	5.0	6.5	7.0	7.6	7.1	6.7
38-m	Surface	8.4	8.4	8.2	8.0	8.1	7.4	8.0	8.0	7.0	7.3	7.8	7.3
	Bottom	6.1	5.6	3.6	4.2	3.7	4.7	4.9	5.6	6.7	7.5	6.7	6.8
55-m	Surface	8.4	8.1	8.3	7.9	8.0	7.5	7.8	8.0	6.9	7.1	7.7	7.3
	Bottom	5.5	4.9	3.7	4.0	3.3	4.6	4.4	4.9	5.6	6.9	6.3	6.2

Table 2.1 *continued*

Depth Contour		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pH													
9-m	Surface	8.1	8.1	8.1	8.2	8.3	8.2	8.2	8.2	8.3	8.3	8.2	8.2
	Bottom	8.1	8.1	8.0	8.1	8.3	8.0	8.0	8.0	8.2	8.2	8.1	8.2
19-m	Surface	8.1	8.2	8.1	8.2	8.3	8.2	8.2	8.2	8.3	8.3	8.2	8.2
	Bottom	8.0	8.0	7.9	7.8	8.1	7.8	7.9	8.0	8.2	8.2	8.2	8.2
28-m	Surface	8.1	8.2	8.2	8.2	8.3	8.1	8.2	8.2	8.2	8.2	8.2	8.2
	Bottom	8.0	7.9	7.8	7.8	7.9	7.8	7.8	8.0	8.1	8.2	8.1	8.2
38-m	Surface	8.1	8.2	8.2	8.1	8.3	8.2	8.2	8.2	8.3	8.2	8.2	8.2
	Bottom	7.9	7.9	7.8	7.8	7.8	7.8	7.8	7.9	8.1	8.2	8.1	8.1
55-m	Surface	8.1	8.1	8.2	8.1	8.3	8.1	8.2	8.1	8.2	8.2	8.1	8.2
	Bottom	7.9	7.9	7.8	7.7	7.7	7.8	7.8	7.8	8.0	8.1	8.1	8.1
Transmissivity (%)													
9-m	Surface	61	76	65	74	69	67	74	67	73	73	68	50
	Bottom	54	74	56	69	67	71	71	77	74	69	59	44
19-m	Surface	72	79	75	77	76	73	77	62	83	78	76	76
	Bottom	43	78	75	73	73	82	78	84	79	74	66	61
28-m	Surface	81	79	76	80	81	85	79	73	90	87	83	87
	Bottom	61	86	85	86	82	89	85	86	89	83	70	76
38-m	Surface	89	83	79	84	83	87	86	75	89	89	89	82
	Bottom	85	89	86	87	87	89	87	89	89	87	82	75
55-m	Surface	88	88	83	87	84	89	87	82	90	90	87	87
	Bottom	91	91	91	91	90	90	90	89	90	89	85	84
Chlorophyll *a* (µg/L)													
9-m	Surface	2.7	7.7	6.2	5.1	14.7	10.0	10.4	10.2	7.7	4.0	5.5	2.4
	Bottom	4.6	13.7	10.1	10.6	21.2	19.8	19.2	12.8	10.2	5.7	9.4	2.8
19-m	Surface	3.0	5.0	5.9	4.5	5.8	7.8	5.1	12.1	1.9	2.4	3.5	1.4
	Bottom	4.1	6.3	4.2	3.3	15.8	10.7	18.1	5.4	8.4	5.9	9.5	1.6
28-m	Surface	2.4	6.4	6.1	2.9	3.9	2.3	5.7	6.2	1.0	1.2	2.4	0.9
	Bottom	3.2	3.7	1.8	2.7	9.3	3.8	9.0	6.3	2.7	5.0	5.7	1.6
38-m	Surface	1.8	2.8	4.3	1.6	1.3	1.5	1.6	3.3	1.0	0.9	1.6	0.6
	Bottom	1.9	2.5	1.1	1.9	4.0	3.6	6.6	3.6	4.2	4.6	3.4	0.7
55-m	Surface	2.4	1.6	3.7	1.7	2.5	1.2	1.7	4.7	1.6	1.2	2.8	0.6
	Bottom	0.8	0.7	0.4	1.0	1.8	2.4	2.0	1.3	2.0	3.7	1.9	0.7

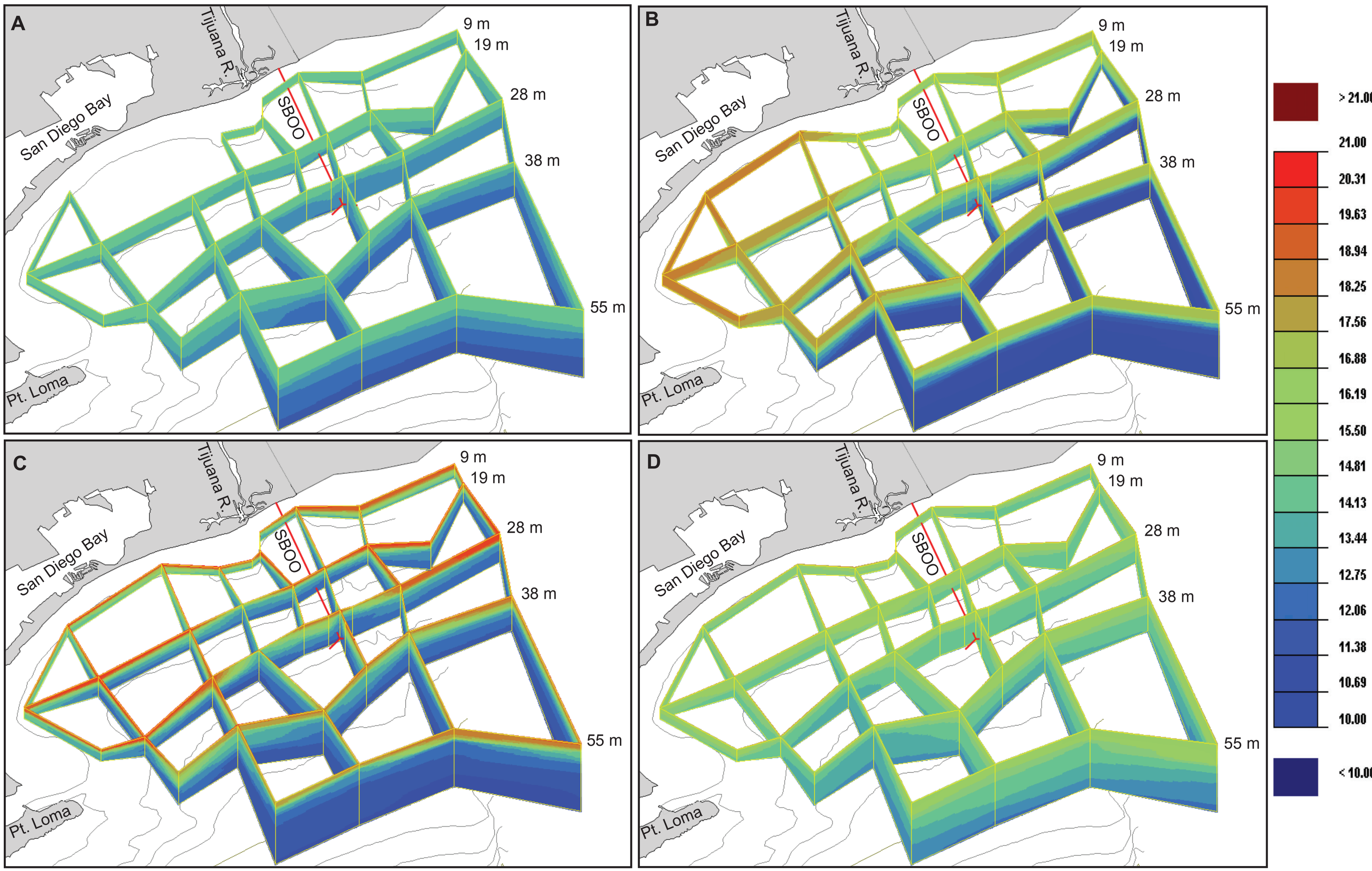


Figure 2.2

Ocean temperatures (°C) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

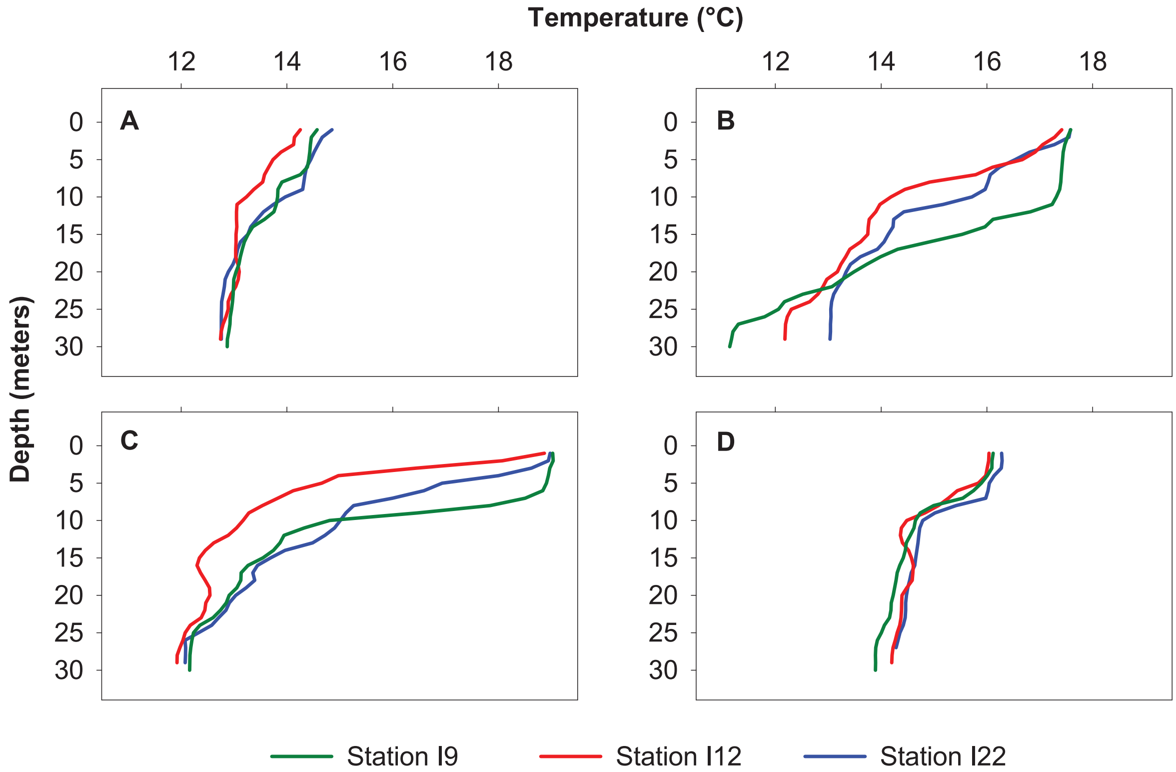


Figure 2.3
Vertical profiles of ocean temperature for SBOO stations I9, I12 and I22 during February (A), May (B), August (C), and November (D) 2009.

temperature at station I12 was colder than at nearby stations I9 and I22 at various depths. For example, temperatures in August at I12 differed by more than 1ºC from the other two stations at depths between about 3 and 17 m. This difference in temperature near the outfall may be due to the force of the effluent exiting the diffusers at depth pushing colder water from the bottom upwards into the water column (i.e., doming). However, it is clear from these analyses that temperature differences between stations at any particular depth were never greater than about 5ºC (Figure 2.3) and this condition was highly localized around the outfall (Figure 2.2).

Salinity

Average salinities for the SBOO outfall region ranged from a low of 33.29 ppt in October to a high of 33.69 ppt in June for surface waters, and from 33.20 ppt in October to 33.81 ppt in May at bottom depths (Table 2.1). High salinity values at bottom depths extended across the entire region in May (Figure 2.5B) and corresponded to the lower temperatures found at bottom depths as described above. Taken together, these factors are indicative of coastal upwelling that is typical for this time of year (Jackson 1986). There was some evidence of another region-wide phenomenon during the summer, when a thin layer of relatively low salinity values occurred at mid-water (i.e., sub-surface) depths between about 10 and 20 m (see Figure 2.5C). It seems unlikely that this sub-surface salinity minima (SSM) could be due to the SBOO discharge for several reasons. For example, corresponding changes indicative of the wastewater plume were not evident in any of the other oceanographic data (e.g., depressed transmissivity). Additionally, no evidence has ever been reported of the plume extending simultaneously throughout the region in so many directions. Instead, results from remote sensing observations (Svejkovsky 2010) and other oceanographic studies (e.g., Terrill et al. 2009) have clearly demonstrated the plume dispersing in specific directions at any one time (e.g., south, southeast, north). Furthermore, bacteriological

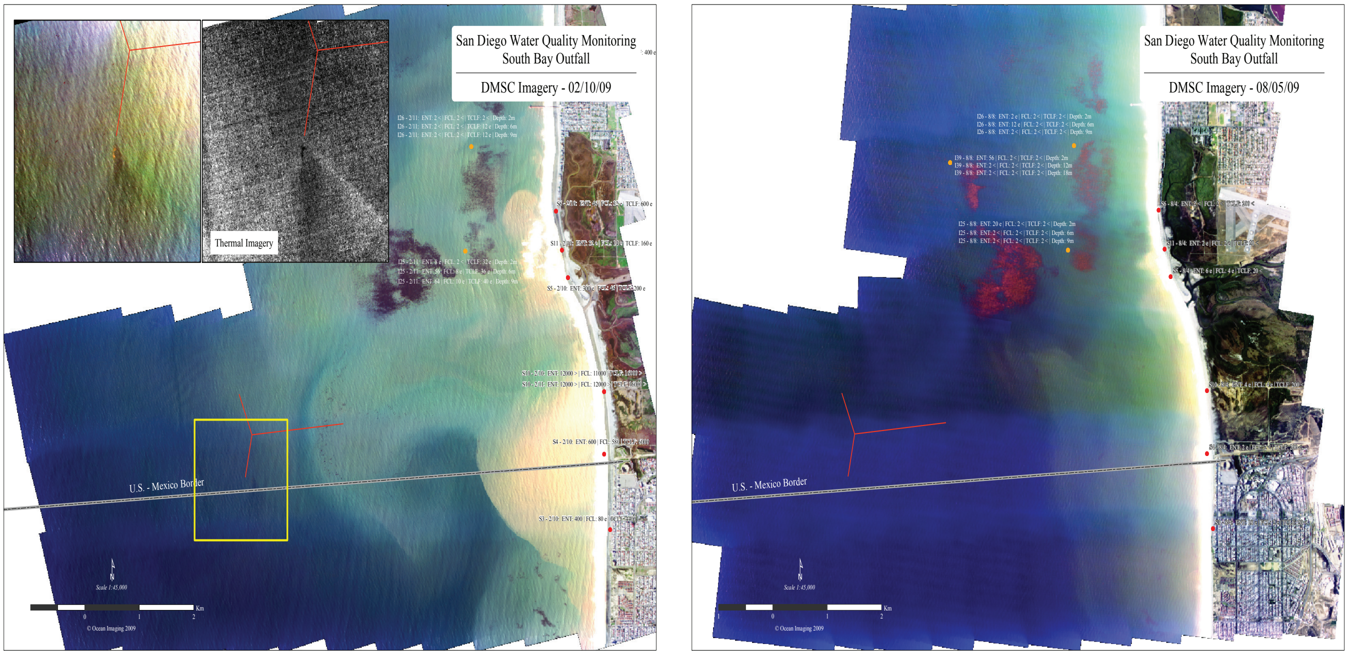


Figure 2.4
DMSC images of the SBOO outfall and coastal region acquired on February 10, 2009, demonstrating when the SBOO plume reaches the surface (left), and on August 5, 2009, demonstrating when the SBOO plume is submerged under the thermocline (right) (see text; images from Ocean Imaging 2010).

samples collected at the same depths and times did not contain elevated levels of indicator bacteria (see Chapter 3). Finally, similar SSMs have been reported previously off San Diego and elsewhere in southern California, including: (1) the Point Loma monitoring region during the summer and fall of 2009 (City of San Diego 2010); (2) coastal waters off Orange County, California for many years (e.g., Orange County Sanitation District 1999); (3) extending as far north as Ventura, California (Orange County Sanitation District 2009). Further investigations are required to determine the possible source (s) of this phenomenon.

In addition to the region-wide phenomena described above, salinity levels were slightly different at stations near the outfall during the year (Figure 2.5, Figure 2.6). Whereas temperatures tended to be relatively low at outfall station I12 during the winter, spring and summer months, salinity was relatively low at this station during the winter, summer and fall. The greatest difference occurred during February when the water column was well mixed; i.e., salinity values at outfall station I12 reached as low as 33.2 ppt, while values remained about 33.4 ppt throughout the water column at stations I9 and I22 to the north and the south (Figure 2.6A), as well as at stations located inshore and offshore of the outfall (Figure 2.5). During the fall, there was some indication of the plume reaching sub-surface waters at station I9 (Figure 2.5B, 2.6B), a pattern which corresponds to the prevailing current patterns for the area (e.g., see Terrill et al. 2009, Svejkovsky 2010). However, low salinity values that occurred in the middle of the water column at both I9 and I22 in August were more likely related to the thin SSM described above. Other stations within the region that had isolated, relatively low salinity levels at mid-depths included the southernmost offshore station (I1) in February and the northernmost offshore station (I28) in November (Figure 2.5A, D).

Density
Seawater density is a product of temperature, salinity and pressure, which in the shallower coastal waters of southern California is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). Therefore, changes in density typically mirror those in water temperatures. This relationship was true in the South Bay region during 2009. For example, differences between surface and bottom

water densities resulted in a moderate pycnocline at depths between about 3–13 m in the spring, a strong pycnocline at depths between 3–7 m in the summer, and a weak pycnocline at depths between 7–10 m in the fall (Appendix A.2, A.3).

Dissolved Oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 6.9 to 9.0 mg/L in surface waters and from 3.3 to 8.2 mg/L in bottom waters across the South Bay region in 2009, while mean pH values ranged from 8.1 to 8.3 in surface waters and from 7.7 to 8.3 in bottom waters (Table 2.1).

Changes in pH were closely linked to changes in DO since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Stratification of the water column also followed normal seasonal patterns for both parameters with the greatest variations and maximum stratification occurring during the spring and summer (Appendix A.4, A.5, A.6). For DO, low bottom water values during the spring across the survey area may be due to the cold, saline and oxygen poor ocean water that moves inshore during periods of coastal upwelling as suggested by temperature and salinity data (see above). In contrast, very high DO values just below the surface (i.e., at the pycnocline) during the spring were likely the result of phytoplankton blooms; these high DO values correspond with high chlorophyll values at these same depths during the same survey.

For both DO and pH, values at outfall station I12 differed from those at stations I9 and I22 (Appendix A.5). As with the variations in temperature and salinity described above, these differences were slight and highly localized (<1.7 mg/L for DO, <0.17 units for pH). The variations were so small, in fact, that they were not apparent in the 3-D graphics (see Appendix A.4, A.6). These changes in DO and pH near the outfall may also be due to doming caused by the force of the effluent pushing bottom waters upwards into the water column.

Transmissivity

Transmissivity appeared to be within normal ranges in the SBOO region during 2009 with average values of 50–90% on the surface and 43–91% in bottom waters (Table 2.1). Water clarity was consistently greater at the offshore monitoring sites than in inshore waters, by as much as 37% at the surface and 39% at the bottom. Reductions in water clarity that occurred at the surface and at mid-depths at stations along the 9, 18 and 28-m depth contours (including stations nearest the outfall) throughout the year tended to co-occur with peaks in chlorophyll concentrations associated with phytoplankton blooms (see Appendix A.7, A.8, A.9; see also Svejkovsky 2010). Lower transmissivity along the 9-m depth contour during the winter and fall months may also have been due to wave and storm activity. Changes in transmissivity levels relative to wastewater discharge were not discernible during the year.

***Chlorophyll* a**

Mean concentrations of chlorophyll *a* ranged from 0.4 µg/L in bottom waters at the offshore sites during March to 21.2 µg/L at inshore bottom depths in May (Table 2.1). However, further analysis clearly showed that the highest chlorophyll values tended to occur in the middle of the water column each season (Appendix A.9). These results reflect the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrient levels are greatest. The highest concentrations of chlorophyll for 2009 occurred during May at mid-depths across much of the region (see Appendix A.9B) and corresponded to the largest phytoplankton bloom observed by remote sensing for the year (Svejkovsky 2010), as well as the coastal upwelling event indicated by the very low temperatures, high salinity and low DO values at bottom depths described above. The relationship between coastal upwelling and subsequent plankton blooms has been well documented by remote sensing imagery over the years (e.g., Svejkovsky 2009, 2010).

In addition to these region-wide mid-depth plankton blooms, relatively high chlorophyll *a* concentrations were apparent at the surface during May and August at the nearshore stations (i.e., along the 9-m depth contour) centered on the mouth of the Tijuana River (Appendix A.9B, C). These higher surface concentrations may be related to a localized

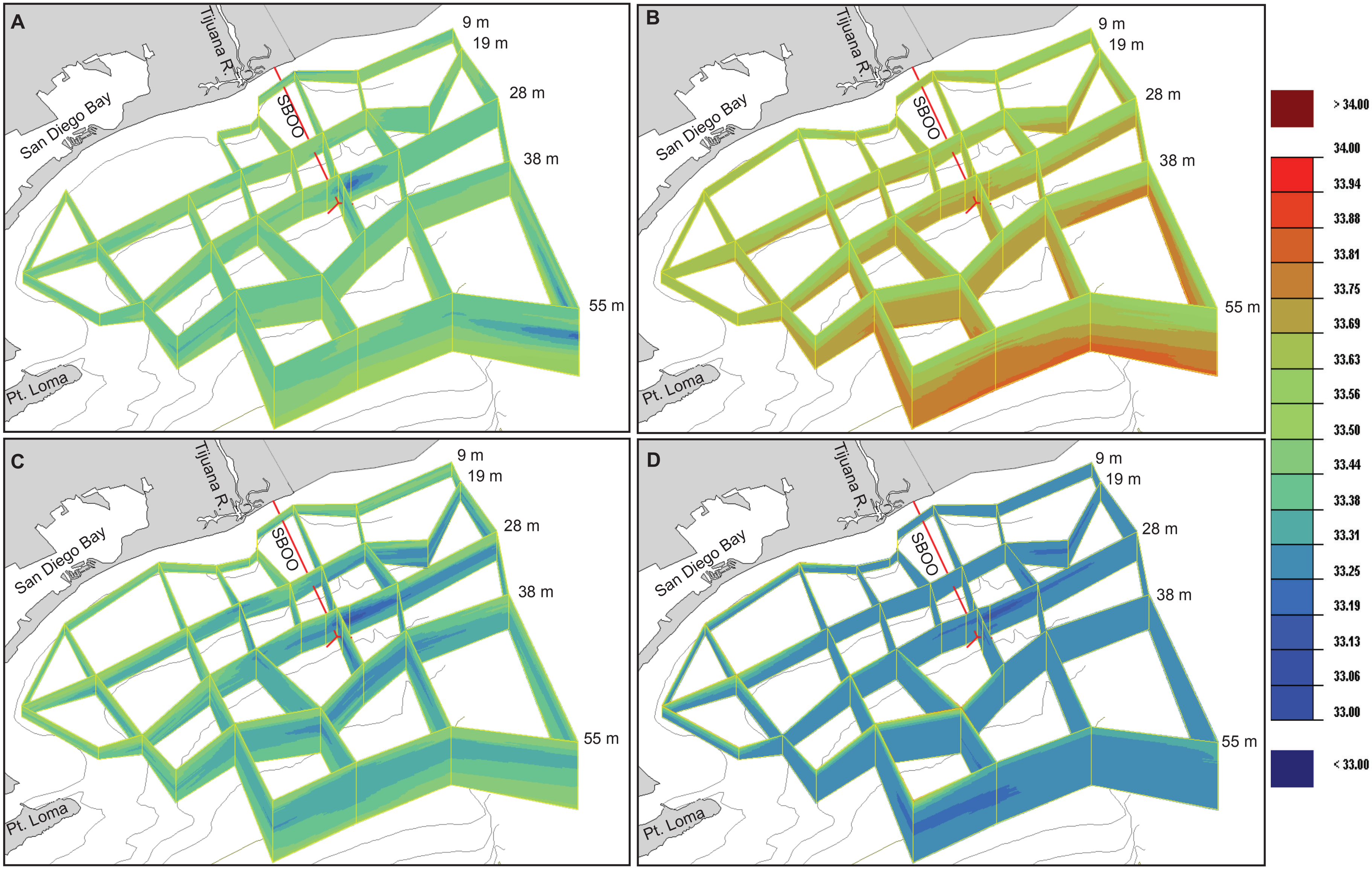


Figure 2.5

Levels of salinity (ppt) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

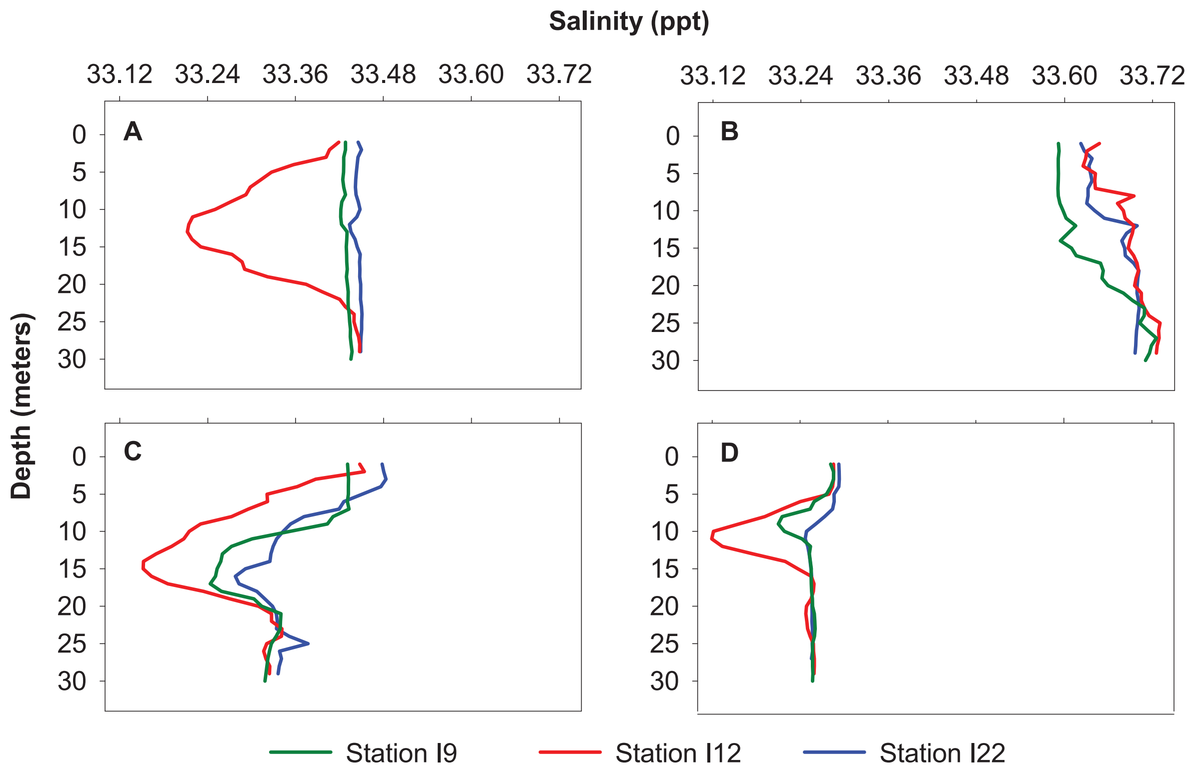


Figure 2.6
Vertical profiles of salinity for SBOO stations I9, I12 and I22 during February (A), May (B), August (C), and November (D) 2009.

phytoplankton bloom in that area depicted in a Landsat TM5 image taken in September (Figure 2.7); a water sample collected on September 16 at station I19 showed a mix of the dinoflagellates *Ceratium* sp and *Lingulodinium polyedrum*. Localized blooms like this are less likely related to nutrient rich waters brought into the area by upwelling, but instead are more likely influenced by the outflow of nutrients with river water that can also stimulate phytoplankton growth (see Gregorio and Pieper 2000).

Historical Assessment of Oceanographic Conditions

A review of oceanographic data between 1995 and 2009 using three representative stations along the 28-m depth contour (i.e., I9, I12, I22) did not reveal any measurable impact that could be attributed to the beginning of wastewater discharge via the SBOO (Figure 2.8). Instead, these data tend to track changes in large scale patterns in the California Current System (CCS) observed by CalCOFI (see Peterson et al. 2006, McClatchie et al. 2008, 2009). For example, five major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño; (2) a shift to cold ocean conditions between 1999–2002; (3) a more subtle but persistent return to warm ocean conditions beginning in October 2002; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 in conjunction with a cooling of the Pacific Decadal Oscillation (PDO). Temperature and salinity data for the South Bay region are consistent with all but the third of these CCS events; i.e., while the CCS was experiencing a warming trend starting in 2002, the SBOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in southern San Diego waters during these two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were well below the decadal mean (Peterson et al. 2006). During 2008 and 2009, temperatures remained cool, but closer to the overall average.

Water clarity (transmissivity) has generally increased in the South Bay region since 1999, although there have been several intermittent

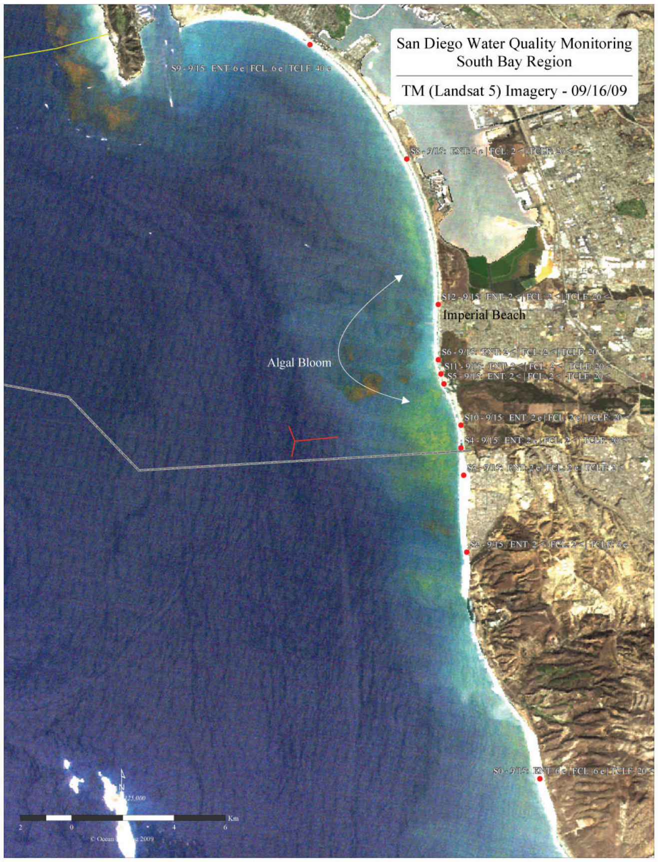


Figure 2.7
Landsat TM5 image of the SBOO outfall and coastal region acquired on September 16, 2009, depicting a localized phytoplankton bloom near the mouth of the Tijuana River (from Ocean Imaging 2010).

periods when clarity was below normal (Figure 2.8). Transmissivity was much lower than normal during the winter months of several years (e.g., 1998, 2000); these periods of low transmissivity are likely due to increased suspension of sediments caused by strong storm activity (see NOAA/NWS 2010). In addition, below average water clarity events that occur in the spring and early summer months are probably related to plankton blooms such as those observed throughout the region in 2005, 2008 and 2009 (see City of San Diego 2006, 2009, and the discussion in the previous section). In contrast, water clarity during 2006 and 2007 was mostly above the historical average. These latter results are indicative of reduced turbidity due to decreased storm activity and lower rainfall totals of less than 11 inches for these two years.

There were no apparent trends in DO concentrations or pH values related to the SBOO discharge (Figure 2.8). These parameters are complex, dependent on water temperature and depth, and sensitive to physico-chemical and biological processes (Skirrow 1975). Moreover, DO and pH are subject to diurnal and seasonal variations that make temporal changes difficult to evaluate. However, DO values below the historical average appear to be related to low levels of chlorophyll or strong upwelling periods.

Summary and Conclusions

The South Bay outfall region was characterized by relatively normal oceanographic conditions in 2009, which included coastal upwelling and corresponding phytoplankton blooms that were strongest during the spring and occurred across the entire region. Upwelling was indicated by relatively cold, dense, saline waters with low DO levels. Plankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations (i.e., aerial and satellite imagery). Additionally, water column stratification followed typical patterns for the San Diego region, with maximum stratification occurring in mid-summer and reduced stratification during the winter. Further, oceanographic conditions for the region remained notably consistent with changes in large scale patterns observed by CalCOFI (e.g., Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009), or they were consistent with data from northern Baja California (e.g., Peterson et al. 2006). These observations suggest that other factors such as upwelling of deep offshore waters and large-scale oceanographic events (e.g., El Niño, La Niña) continue to explain most of the temporal and spatial variability observed in water quality parameters off southern San Diego.

As expected, satellite and aerial imagery detected the signature of the SBOO wastewater plume in near-surface waters above the discharge site on several occasions between January–March and November–December when the water column was well mixed (Svejkovsky 2010). In contrast, the plume appeared to remain deeply submerged between April–October when the water column was stratified. Results from

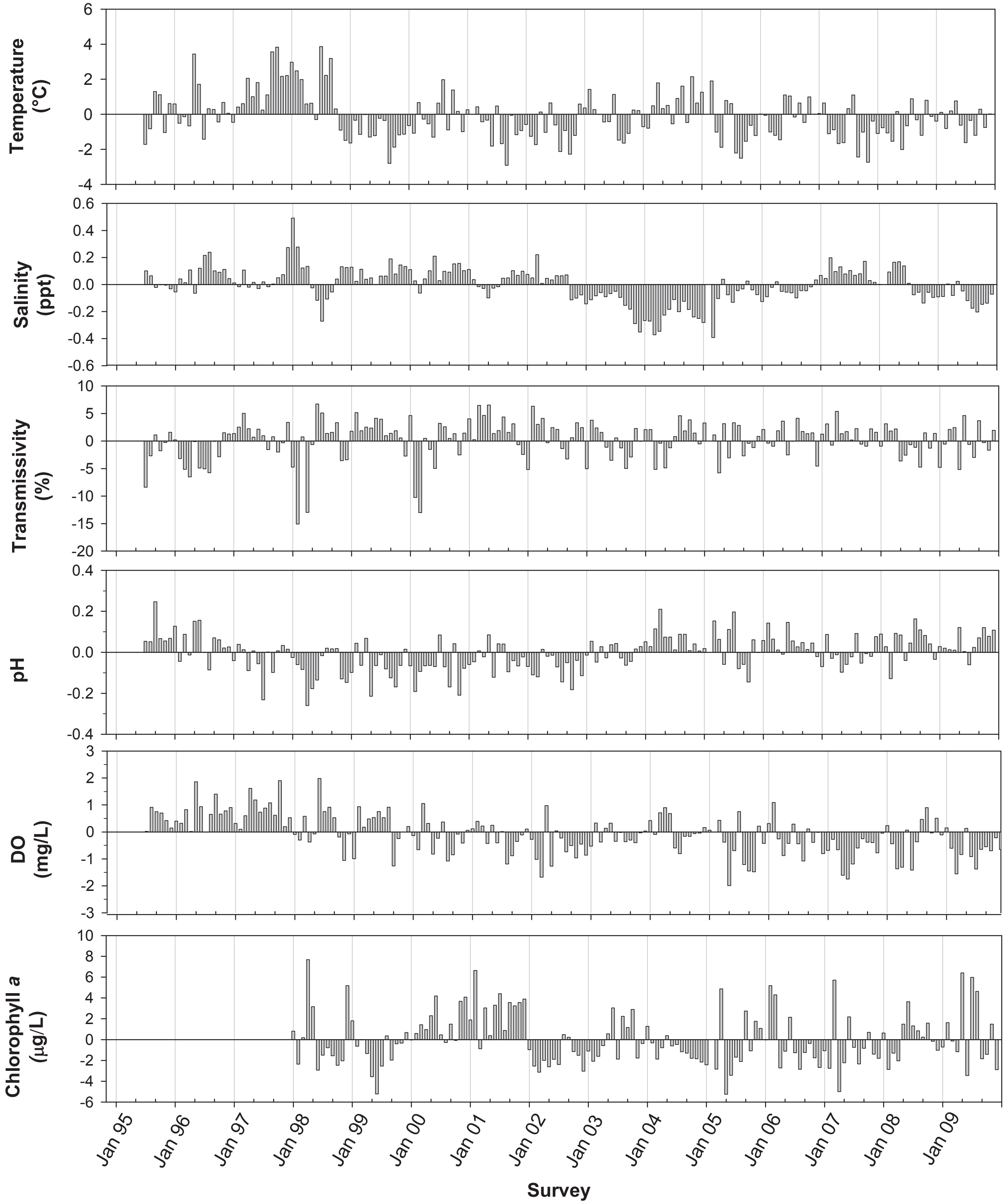


Figure 2.8

Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll anomalies between 1995 and 2009. Anomalies were calculated by subtracting the monthly means for each year (1995–2009) from the mean of all years combined; data were limited to stations I9, I12, and I22, all depths combined.

bacteriological surveys further support the conclusion that the plume reached surface or near-surface waters only during the winter months when the water column was well-mixed (see Chapter 3). In addition, historical analysis of remote sensing observations made between 2003 and 2009 suggest that the wastewater plume from the SBOO has never reached the shoreline (Svejkovsky 2010). These findings were supported this past year by the application of new IGODS analytical techniques to the oceanographic data collected by the City's ocean monitoring program. While small differences were observed at stations close to the outfall discharge site, it was clear from these analyses that any variations among stations at any particular depth were very slight and highly localized.

Literature Cited

Bowden, K.F. (1975). Oceanic and Estuarine Mixing Processes. In: J.P. Riley and G. Skirrow (eds.). Chemical Oceanography, 2nd Ed., Vol.1. Academic Press, San Francisco. p 1–41.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Dailey, M.D., D.J. Reish, and J.W. Anderson, eds. (1993). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

Goericke, R., E. Venrick, T. Koslow, W.J. Sydeman, F.B. Schwing, S.J. Bograd, B. Peterson, R. Emmett, K.R. Lara Lara, G. Gaxiola-Castro, J.G. Valdez, K.D. Hyrenbach, R.W. Bradley, M. Weise, J. Harvey, C. Collins, and N. Lo. (2007). The state of the California Current, 2006–2007: Regional and local processes dominate. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 48: 33–66.

Gregorio, E. and R.E. Pieper. (2000). Investigations of red tides along the Southern California coast. Southern California Academy of Sciences Bulletin, 99(3): 147–160.

Jackson, G.A. (1986). Physical Oceanography of the Southern California Bight. In: R. Eppley (ed.). Plankton Dynamics of the Southern California Bight. Springer Verlag, New York. p 13–52.

Largier, J., L. Rasmussen, M. Carter, and C. Scearce. (2004). Consent Decree – Phase One Study Final Report. Evaluation of the South Bay International Wastewater Treatment Plant Receiving Water Quality Monitoring Program to Determine Its Ability to Identify Source(s) of Recorded Bacterial Exceedances. Scripps Institution of Oceanography, University of California, San Diego, CA.

Mann, K.H. (1982). Ecology of Coastal Waters, A Systems Approach. University of California Press, Berkeley.

Mann. K.H. and J.R.N. Lazier. (1991). Dynamics of Marine Ecosystems, Biological–Physical Interactions in the Oceans. Blackwell Scientific Publications, Boston.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, G. Gaxiola-Castro, R. Durazo, M. Kahru, B.G. Mitchell, K.D. Hyrenbach, W.J. Sydeman, R.W. Bradley, P. Warzybok, and E. Bjorkstedt. (2008). The state of the California Current, 2007–2008: La Niña conditions and their effects on the ecosystem. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 49: 39–76.

McClatchie, S., R. Goericke, J.A. Koslow, F.B. Schwing, S.J. Bograd, R. Charter, W. Watson, N. Lo, K. Hill, J. Gottschalck, M. l'Heureux, Y. Xue, W.T. Peterson, R. Emmett, C. Collins, J. Gomez-Valdes, B.E. Lavaniegos, G. Gaxiola-Castro, B.G. Mitchell, M. Manzano-Sarabia, E. Bjorkstedt. S. Ralston, J. Field, L. Rogers-Bennet, L. Munger, G. Campbell, K. Merkens, D. Camacho, A. Havron, A. Douglas, and J. Hildebrand (2009). The state of the California Current, Spring 2008–2009: Cold conditions drive regional differences in coastal production. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 50: 43–68.

NOAA/NWS. (2010). The National Oceanic and Atmospheric Association and the National Weather Service Archive of Local Climate Data for San Diego, CA. http://www.wrh.noaa.gov/sgx/obs/rtp/linber.html.

Ocean Imaging. (2010). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

Orange County Sanitation District. (1999). Annual Report, July 1998–June 1999. Marine Monitoring, Fountain Valley, CA.

Orange County Sanitation District. (2009). Annual Report, July 2008–June 2009. Marine Monitoring, Fountain Valley, CA.

Peterson, B., R. Emmett, R. Goericke, E. Venrick, A. Mantyla, S.J. Bograd, F.B. Schwing, R. Hewitt, N. Lo, W. Watson, J. Barlow, M. Lowry, S. Ralston, K.A. Forney, B.E. Lavaniegos, W.J. Sydeman, D. Hyrenbach, R.W. Bradley, P. Warzybok, F. Chavez, K. Hunter, S. Benson, M. Weise, J. Harvey, G. Gaxiola-Castro, and R. Durazo. (2006). The state of the California Current, 2005–2006: Warm in the north, cool in the south. California Cooperative Oceanic Fisheries Investigations (CalCOFI) Reports, 47: 30–74.

Pickard, D.L. and W.J. Emery. (1990). Descriptive Physical Oceanography. 5th Ed. Pergamon Press, Oxford.

Skirrow, G. 1975. Chapter 9. The Dissolved Gases–Carbon Dioxide. In: Chemical Oceanography. J.P. Riley and G. Skirrow, eds. Academic Press, London. Vol. 2. p 1–181.

Svejkovsky J. (2009). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2008 – 31 December 2008. Solana Beach, CA.

Svejkovsky J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report for: 1 January 2009 – 31 December 2009. Solana Beach, CA.

Terrill, E., K. Sung Yong, L. Hazard, and M. Otero. (2009). IBWC/Surfrider – Consent Decree Final Report. Coastal Observations and Monitoring in South Bay San Diego. Scripps Institution of Oceanography, University of California, San Diego, CA.

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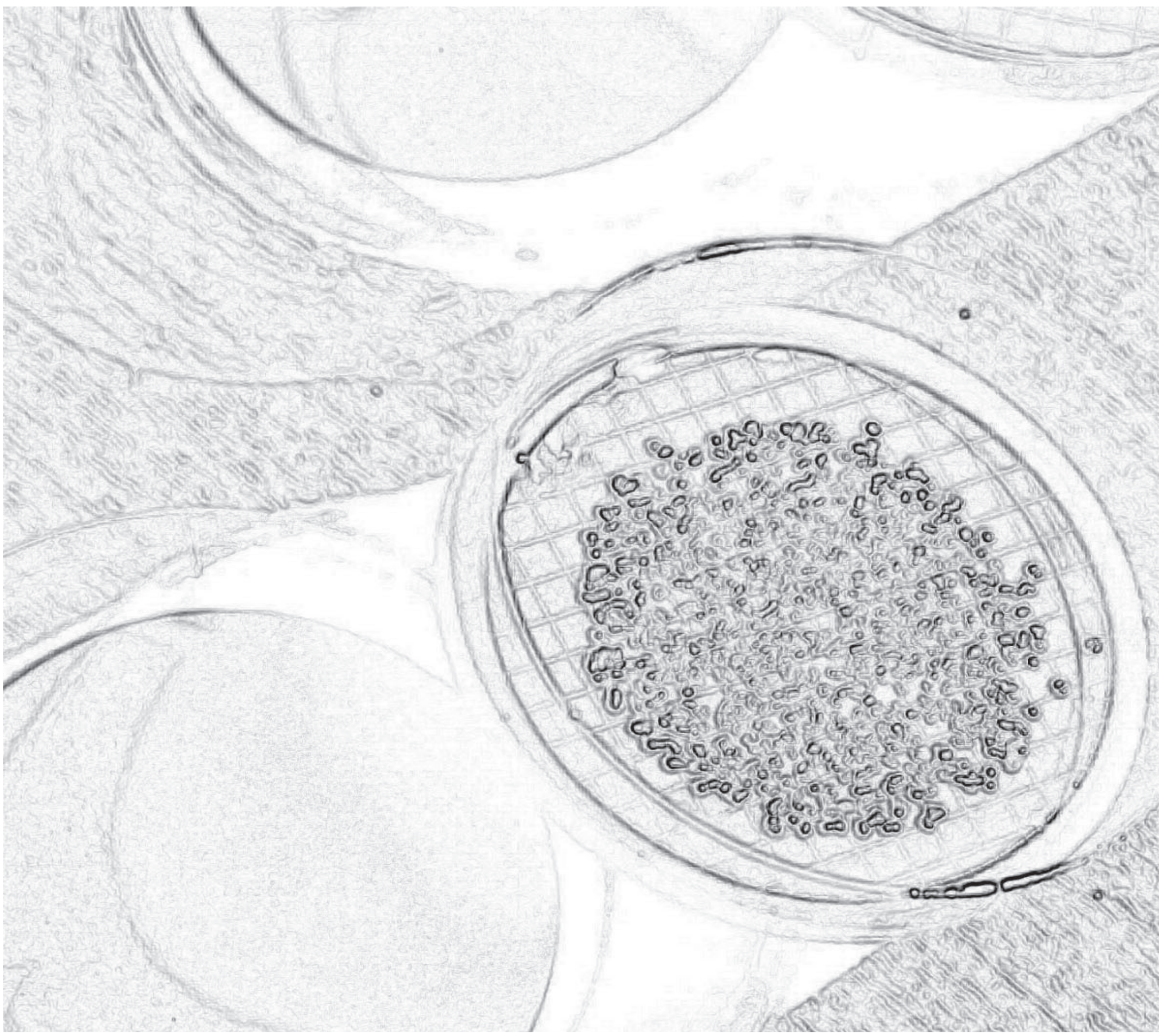
Chapter 3
Water Quality



Chapter 3. Water Quality

INTRODUCTION

The City of San Diego monitors water quality along the shoreline and in offshore ocean waters for the region surrounding the South Bay Ocean Outfall (SBOO). This aspect of the City's ocean monitoring program is designed to assess general oceanographic conditions, evaluate patterns in movement and dispersal of the SBOO wastewater plume, and monitor compliance with water contact standards as defined in the 2001 California Ocean Plan (COP) (see Chapter 1). Results of all sampling and analyses, including COP compliance summaries, are submitted to the San Diego Regional Water Quality Control Board in the form of monthly receiving waters monitoring reports. Densities of fecal indicator bacteria (FIB), including total coliforms, fecal coliforms, and enterococcus, are measured and evaluated along with data on local oceanographic conditions (see Chapter 2) to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall. Evaluation of these data may also help to identify other point or non-point sources of bacterial contamination (e.g., outflows from rivers or bays, surface runoff from local watersheds). This chapter summarizes and interprets patterns in seawater FIB concentrations collected for the South Bay region during 2009. In addition, this chapter assesses remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site.

Materials and Methods

Field Sampling

Seawater samples for bacteriological analyses were collected at a total of 39 shore, kelp bed, or other offshore monitoring sites during 2009 (Figure 3.1). Sampling was performed weekly at 11 shore stations to monitor FIB concentrations in waters adjacent to public beaches. Eight of these stations (S4, S5, S6, S8, S9, S10, S11, S12) are located between the USA/Mexico border and Coronado, southern California and are subject to COP water contact standards (see Box 3.1). The other three shore stations (S0, S2, S3) are located in Mexican waters off northern Baja California and are not subject to COP requirements. Three stations located in nearshore waters within the Imperial Beach kelp forest were also monitored weekly to assess water quality conditions and COP compliance in areas used for recreational activities such as SCUBA diving, surfing, fishing, and kayaking. These include stations I25 and I26 located near the inner edge of the kelp bed along the 9-m depth contour, and station I39 located near the outer edge of the kelp bed along the 18-m depth contour. An additional 25 stations located further offshore in deeper waters were sampled once a month in order to monitor FIB levels and estimate the spatial extent of the wastewater plume. These offshore stations are arranged in a grid surrounding the discharge site distributed along the 9, 19, 28, 38, and 55-m depth contours (Figure 3.1). Sampling of these offshore stations generally occurs over a 3-day period each month.

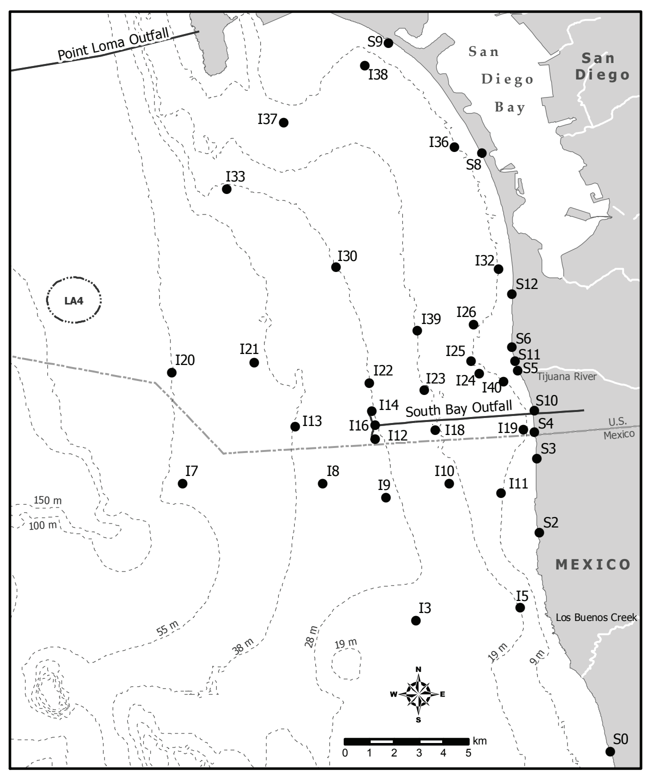


Figure 3.1
Water quality monitoring stations for the South Bay Ocean Outfall Monitoring Program.

Box 3.1

Bacteriological compliance standards for water contact areas, 2001 California Ocean Plan (SWRCB 2001). CFU = colony forming units.

(a) *30-day Total Coliform Standard* — no more than 20% of the samples at a given station in any 30-day period may exceed a concentration of 1000 CFU per 100 mL.

(b) *10,000 Total Coliform Standard* — no single sample, when verified by a repeat sample collected within 48 hrs, may exceed a concentration of 10,000 CFU per 100 mL.

(c) *60-day Fecal Coliform Standard* — no more than 10% of the samples at a given station in any 60-day period may exceed a concentration of 400 CFU per 100 mL.

(d) *30-day Fecal Geometric Mean Standard* — the geometric mean of the fecal coliform concentration at any given station in any 30-day period may not exceed 200 CFU per 100 mL, based on no fewer than five samples.

Seawater samples for the shore stations were collected from the surf zone in sterile 250-mL bottles. In addition, visual observations of water color, surf height, human or animal activity, and weather conditions were recorded at the time of collection. The samples were then transported on blue ice to the City of San Diego's Marine Microbiology Laboratory (CSDMML) and analyzed to determine FIB concentrations (i.e., total coliform, fecal coliform, and enterococcus bacteria).

Either an array of Van Dorn bottles or a rosette sampler fitted with Niskin bottles was used to collect seawater samples at each of the kelp bed and other offshore stations. Samples were collected at three discrete depths for the above FIBs (i.e., total and fecal coliforms, enterococcus) and total suspended solids (TSS), whereas oil and grease (O&G) samples were only collected from surface waters. Aliquots for each analysis were drawn into appropriate sample containers. All bacterial seawater samples were refrigerated onboard ship and transported to the CSDMML for subsequent processing and analysis. TSS and O&G samples were taken to the City's Wastewater Chemistry Services Laboratory for analysis. Visual observations of weather and sea conditions, and human or animal activity were also recorded at the time of sampling.

Laboratory Analyses and Data Treatment

All bacterial analyses were performed within 8 hours of sample collection and conformed to standard membrane filtration techniques (see APHA 1998). The CSDMML follows guidelines issued by the United States Environmental Protection Agency (U.S. EPA) Water Quality Office, Water Hygiene Division, and the California State Department of Health Services (CDHS) Environmental Laboratory Accreditation Program (ELAP) with respect to sampling and analytical procedures (Bordner et al. 1978, APHA 1998).

Procedures for counting colonies of indicator bacteria, calculation and interpretation of results, data verification and reporting all follow guidelines established by the U.S. EPA (Bordner et al. 1978) and APHA (1998). According to these guidelines, plates with FIB counts above or below the ideal counting range were given greater than (>), less than (<), or estimated (e) qualifiers. However, these qualifiers were dropped and the counts treated as discrete values when calculating means and in determining compliance with COP standards.

Quality assurance tests were performed routinely on seawater samples to ensure that sampling variability did not exceed acceptable limits. Duplicate and split bacteriological samples were processed according to method requirements to measure intrasample and inter-analyst variability, respectively. Results of these procedures were reported in City of San Diego (2010).

Bacteriological benchmarks defined in the 2001 COP and Assembly Bill 411 (AB 411) were used as reference points to distinguish elevated FIB values in receiving water samples discussed in this report. These benchmarks are: (a) >1000 CFU/100 mL for total coliforms; (b) >400 CFU/100 mL for fecal coliforms; (c) >104 CFU/100 mL for enterococcus. Data were summarized for analysis as counts of samples in which FIB concentrations exceeded any of these benchmarks. Furthermore, any water sample with a total coliform concentration ≥1000 CFU/100 mL and a fecal:total (F:T) ratio ≥0.1 was considered representative of contaminated waters (see CDHS 2000). This condition is referred to as the fecal:total ratio (FTR) criteria herein. In addition, statistical analyses were conducted to determine if the proportion of shore samples with elevated FIBs or samples that met the criteria for contamination correlated with rainfall on an annual basis between 1996 and 2009. To meet the assumption of linearity and homogeneity of variances for the correlations, FIB and FTR data were arcsine transformed. This relationship was further investigated by comparing elevated total coliform concentrations to aerial and satellite images produced by Ocean Imaging of Solana Beach, California (Ocean Imaging 2010).

Results and Discussion

Shore Stations

Concentrations of indicator bacteria generally were lower along the South Bay shoreline in 2009 than in 2008 (see City of San Diego 2009), which likely reflects less rainfall during the past year (i.e., 5.5 inches in 2009 vs. 12.1 inches in 2008). During 2009, monthly FIB densities averaged from < 2 to 13,350 CFU/100 mL for total coliforms, <2 to 9012 CFU/100 mL for fecal coliforms, and <2 to 7025 CFU/100 mL for enterococcus (Appendix B.1). As expected, most samples with elevated FIBs (81 of 85 samples) and that exceeded FTR criteria (40 of 42 samples) were collected in the wet season primarily during January, February, and December (Table 3.1; Appendix B.2). These high FIB counts tend to correspond with turbidity plumes from the Tijuana River and Los Buenos Creek (in Mexico), which have been observed repeatedly over the past several years following rain events (e.g., see City of San Diego 2008, 2009). For example, a MODIS satellite image taken February 18 showed turbidity plumes encompassing all of the SBOO shore stations, 10 of which had elevated total coliform concentrations on the previous day (Figure 3.2). While the image in this figure was not taken on the same day the bacterial samples were collected, the turbidity

Table 3.1
The number of samples with elevated bacteria collected at SBOO shore stations during 2009. Elevated FIB = the total number of samples with elevated FIB densities; contaminated = the total number of samples that meet the fecal:total coliform ratio criteria indicative of contaminated seawater; Wet = January–April and November–December; Dry = May–October; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Stations are listed north to south from top to bottom.

Station		Season		Total
		Wet	Dry	
S9	Elevated FIB	—	—	—
	Contaminated	1	—	1
S8	Elevated FIB	3	—	3
	Contaminated	2	—	2
S12	Elevated FIB	4	—	4
	Contaminated	2	—	2
S6	Elevated FIB	6	—	6
	Contaminated	2	—	2
S11	Elevated FIB	5	—	5
	Contaminated	5	—	5
S5	Elevated FIB	11	—	11
	Contaminated	9	—	9
S10	Elevated FIB	12	—	12
	Contaminated	6	—	6
S4	Elevated FIB	11	—	11
	Contaminated	6	—	6
S3	Elevated FIB	10	—	10
	Contaminated	2	—	2
S2	Elevated FIB	7	1	8
	Contaminated	2	—	2
S0	Elevated FIB	12	3	15
	Contaminated	3	2	5
	Rain (in)	5.43	0.07	5.50
Total Counts	Elevated FIB	81	4	85
	Contaminated	40	2	42
	n	286	286	572

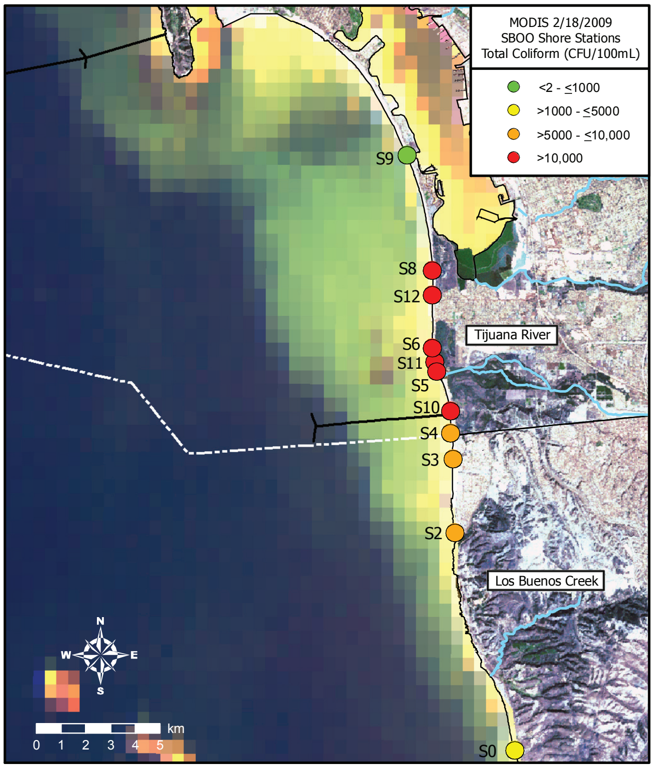


Figure 3.2
MODIS satellite image showing the SBOO monitoring region on February 18, 2009 (Ocean Imaging 2010) combined with total coliform concentrations at shore stations sampled on February 17, 2009. Turbid waters from the Tijuana River and Los Buenos Creek can be seen moving northwest along the coastline, overlapping southern stations with higher levels of contamination. Waters are relatively clear over the outfall discharge site.

plume that is evident likely started earlier in the week due to a major storm that began February 16.

The general relationship between rainfall, elevated FIBs, and the number of contaminated samples has remained consistent since monitoring began in 1995 (see City of San Diego 2009). This relationship is further supported by the strong correlation between the proportion of samples with elevated FIBs and annual rainfall from 1996 to 2009 ($r = 0.72$, $p = 0.004$, Figure 3.3A) and between the proportion of samples that met the FTR contamination criteria and annual rainfall for the same time period ($r = 0.81$, $p < 0.001$, Figure 3.3B). In 2009, this relationship was particularly evident at stations S3–S6, S10, S11 near the Tijuana River and stations S0 and S2 near Los Buenos Creek (see Table 3.1). Historically, elevated FIB densities have occurred much more frequently at these eight shore stations than stations S8, S9, and S12 located further north (see City of San Diego 2007). It is well established that contaminated waters originating from the Tijuana River and Los Buenos Creek are likely sources of bacteria during periods of increased flows (e.g., during storms or extreme tidal exchanges) (see Noble et al. 2003, Largier et al. 2004, Gersberg et al. 2008, Terrill et al. 2009). Such contaminants may originate from various sources, including sod farms, surface runoff not captured by the canyon collection system, the Tijuana estuary (e.g., decaying plant

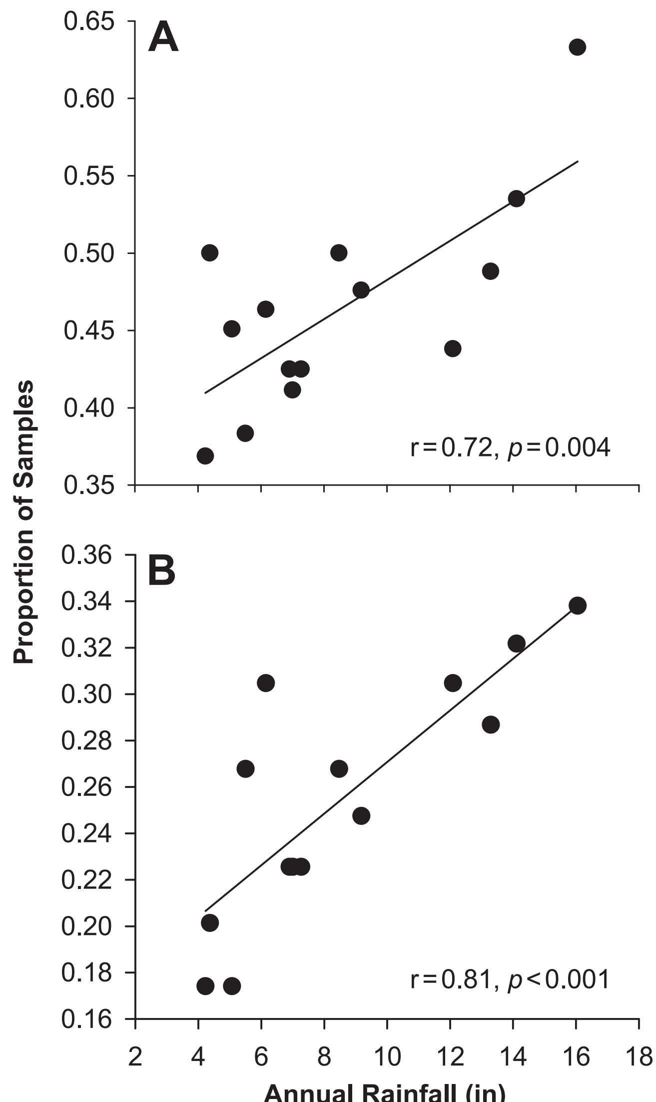


Figure 3.3
Relationship between annual rainfall from 1996 to 2009 and the proportion of elevated FIBs (A) and the proportion of samples that met the FTR criteria for contaminated seawater (B). Note that the data have been arcsine transformed. Rain was measured at Lindbergh Field, San Diego, CA.

material), and partially treated effluent from the San Antonio de los Buenos Wastewater Treatment Plant (SABWTP).

Bacterial contamination that occurred along the shore during periods of warmer, dry conditions between May–October occurred at only a few of the most southern stations (see Table 3.1). For example, the four samples with elevated FIB densities that were not associated with rainfall occurred at stations S0 and S2, both of which are located south of the international border. There are several potential sources of FIBs near these stations, including uncontrolled residential and commercial discharge points in Mexico and/or northward transport of SABWTP associated wastewater discharge to the ocean via Los Buenos Creek (Terrill et al. 2009).

Kelp Bed Stations

There was no evidence that the wastewater plume from the SBOO impacted the three kelp bed stations in 2009. Instead, elevated FIB densities at these sites corresponded to periods of heavy rainfall similar to the pattern seen along the shore. For example, all but one sample with elevated FIBs and all samples that met the FTR criteria at these stations occurred during the wet season (Table 3.2). High FIB counts in the kelp bed also tend to correspond with turbidity plumes from the Tijuana River and Los Buenos Creek (in Mexico). For example, a MODIS satellite image taken February 18 showed turbidity plumes encompassing all of the SBOO kelp stations, two of which had elevated total coliform concentrations on the previous day (Figure 3.4). As mentioned above, this turbidity plume likely started earlier in the week due to a major storm that began February 16. In contrast, only one seawater sample collected in the dry season from these stations contained elevated levels of FIB (Appendix B.3).

Additionally, about half of the elevated FIBs reported at the kelp bed stations were for total coliform bacteria (i.e., 11 of 19 samples); 7 of these 11 samples also had elevated fecal coliforms, of which 4 also exceeded the FTR criteria. Densities of enterococcus bacteria were elevated in 18 samples, 8 of which did not co-occur with elevated total or fecal coliforms.

Table 3.2
The number of samples with elevated bacteria collected at SBOO kelp stations during 2009. Elevated FIB = the total number of samples with elevated FIB densities; contaminated = the total number of samples that meet the fecal:total coliform ratio criteria indicative of contaminated seawater; Wet = January–April and November–December; Dry = May–October; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA.

Station	Depth		Season: Wet	Season: Dry	Total
I25	2 m	Elevated FIB	2	1	3
		Contaminated	1	—	1
	6 m	Elevated FIB	4	—	4
		Contaminated	—	—	—
	9 m	Elevated FIB	4	—	4
		Contaminated	1	—	1
I26	2 m	Elevated FIB	2	—	2
		Contaminated	1	—	1
	6 m	Elevated FIB	2	—	2
		Contaminated	—	—	—
	9 m	Elevated FIB	2	—	2
		Contaminated	—	—	—
I39	2 m	Elevated FIB	—	—	—
		Contaminated	—	—	—
	12 m	Elevated FIB	—	—	—
		Contaminated	—	—	—
	18 m	Elevated FIB	2	—	2
		Contaminated	1	—	1
Total Counts		Rain (in)	5.43	0.07	5.50
		Elevated FIB	18	1	19
		Contaminated	4	—	4
		n	270	270	540

Total suspended solids (TSS) and oil and grease (O&G) are also measured at the kelp bed stations as potential indicators of wastewater. However, previous analyses have demonstrated that these parameters have limited utility as indicators of the wastefield (City of San Diego 2007). TSS varied considerably during 2009, ranging between 1.8 and 29.9 mg/L per sample (Table 3.3), while O&G was not detected in any samples. Of the 44 seawater samples with elevated TSS concentrations

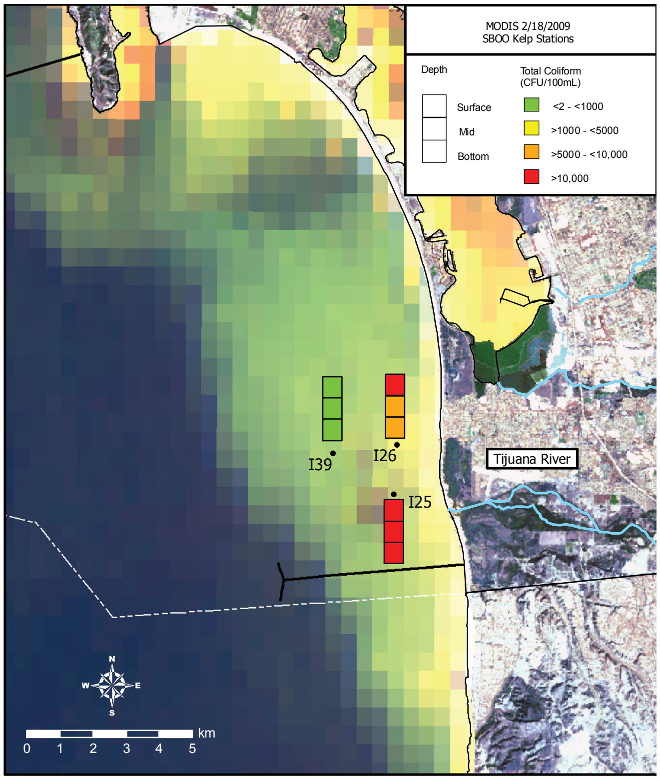


Figure 3.4
MODIS satellite image showing the SBOO monitoring region on February 18, 2009 (Ocean Imaging 2010) combined with total coliform concentrations at kelp stations sampled on February 17, 2009. Turbid waters from the Tijuana River and Los Buenos Creek can be seen moving northwest along the coastline overlapping the kelp bed stations. Waters are relatively clear over the outfall discharge site.

(≥8.0 mg/L), only two corresponded to samples with elevated FIBs. In contrast, 18 of these high TSS samples occurred at bottom depths, likely due to the re-suspension of bottom sediments when the CTD reached (touched) the sea floor. The remaining 26 high TSS values were found in surface-water and mid-water samples, and tended to be associated either with the presence of phytoplankton blooms or runoff from storm activity that occurred around the time of sampling.

Offshore Stations

Elevated FIB concentrations were rare in samples collected from the 25 non-kelp bed offshore stations during 2009. Only 51 of 897 samples (~5.7%) collected at these sites had elevated FIBs and 22 (~2.5%) met the FTR criteria for contaminated waters (Table 3.4, Appendix B.4). Most samples with elevated FIB levels were collected during the wet season at stations located along the 9 and 19-m depth contours (i.e., stations I5, I11, I18, I19, I24, I32, I40). As with the shore and kelp bed stations, the results from MODIS satellite imaging suggests that the nearshore region is affected by contaminants (turbidity plumes) originating from the Tijuana River and Los Buenos Creek. For example, a MODIS satellite image taken December 18, 2009 showed a turbidity plume associated with increased rainfall moving northwest and encompassing stations I19, I24 and I40 (Figure 3.5). Samples collected that day at these three stations had elevated total coliform densities at one or more depths, whereas the majority of samples collected farther offshore (i.e., stations I14, I16, I18, I22, I23) had low FIB levels. In contrast, only seven samples with elevated FIBs were collected during the dry season at the non-outfall stations. These included one or more samples each from stations I9 and I18 located south of the outfall along the 28 and 19-m depth contours, respectively, and one sample each from stations I22, I30, and I33 located north of the outfall along the 28-m depth contour (see Appendix B.4). One sample with elevated FIBs was collected at station I5 located along the

Table 3.3
Summary of total suspended solid (TSS) concentrations in samples collected from the SBOO kelp bed stations in 2009. Data include the number of detected values (*n*), as well as minimum (Min), maximum (Max), and mean detected concentrations for each month. The method detection limit = 1.6 mg/L for TSS.

	n	Min	Max	Mean
January	9	3.4	22.1	9.6
February	9	3.1	6.8	4.6
March	9	1.8	12.9	5.7
April	9	5.1	10.3	7.9
May	9	7.0	20.2	10.7
June	9	3.0	8.4	5.9
July	9	4.4	9.1	6.7
August	9	3.3	11.3	5.9
September	9	5.6	17.3	8.4
October	9	7.1	19.3	12.9
November	9	5.1	17.9	9.3
December	9	4.4	29.9	11.6

Table 3.4
The number of samples with elevated bacteria collected at SBOO offshore stations during 2009. Elevated FIB = the total number of samples with elevated FIB densities; contaminated = the total number of samples that meet the fecal:total coliform ratio criteria indicative of contaminated seawater; Wet = January–April and November–December; Dry = May–October; *n* = total number of samples. Rain data are from Lindbergh Field, San Diego, CA. Offshore stations not listed had no samples with elevated FIB concentrations.

Station		Season		
		Wet	Dry	Total
9-m Depth Contour				
I11	Elevated FIB	6	—	6
	Contaminated	2	—	2
I19	Elevated FIB	7	—	7
	Contaminated	1	—	1
I24	Elevated FIB	1	—	1
	Contaminated	—	—	—
I32	Elevated FIB	2	—	2
	Contaminated	—	—	—
I40	Elevated FIB	4	—	4
	Contaminated	1	—	1
19-m Depth Contour				
I5	Elevated FIB	2	1	3
	Contaminated	—	—	—
I18	Elevated FIB	1	1	2
	Contaminated	—	—	—
28-m Depth Contour				
I9	Elevated FIB	2	1	3
	Contaminated	—	1	1
I12	Elevated FIB	9	3	12
	Contaminated	8	3	11
I14	Elevated FIB	1	2	3
	Contaminated	—	1	1
I16	Elevated FIB	2	2	4
	Contaminated	2	2	4
I22	Elevated FIB	—	1	1
	Contaminated	—	—	—
I30	Elevated FIB	—	1	1
	Contaminated	—	—	—
I33	Elevated FIB	1	1	2
	Contaminated	1	—	1
	Rain (in)	5.43	0.07	5.50
Total Counts	Elevated FIB	38	13	51
	Contaminated	15	7	22
	n	252	252	504

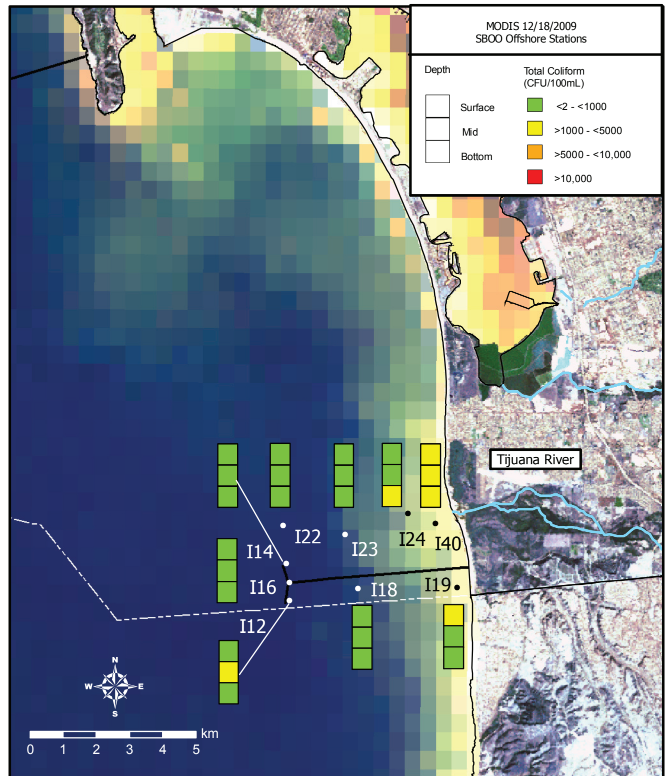


Figure 3.5
MODIS satellite image showing the SBOO monitoring region on December 18, 2009 (Ocean Imaging 2010) combined with total coliform concentrations at offshore stations sampled on the same day. Turbid waters from the Tijuana River and Los Buenos Creek can be seen moving north along the coastline and overlapping stations where contamination was high nearshore. Waters are clear over the outfall discharge site.

19-m depth contour in Mexican waters. Elevated FIB levels at I5 during the current and previous years (e.g., see City of San Diego 2007) are likely related to contaminated outflows from the nearby Los Buenos Creek.

During 2009, a total of 19 samples with elevated FIB densities were collected at sites adjacent to the SBOO diffusers (i.e., stations I12, I14, I16). Most of these samples were collected from a depth of 18 m or greater, and most also met the FTR criteria for contaminated waters (see Appendix B.4). Consequently, it appears likely that these FIB densities were associated with wastewater discharge from the outfall. Further, two samples with elevated FIBs were collected in surface waters during the year; both of these were collected at station I12 in February and were likely associated with the surfacing of the wastewater plume in the winter.

Aerial imagery results support this conclusion, as they indicated that the wastewater plume reached near-surface waters above the discharge site on several occasions between January–April and November–December (Svejkovsky 2010). The low incidence of contaminated waters during winter at the surface and at depth may be due to chlorination of IWTP effluent, which typically occurs between November and April each year. The lack of elevated bacteria levels in surface waters during the summer is expected, as those are the months when the water column is well stratified and the wastefield remains trapped beneath the thermocline.

Like the kelp bed stations, TSS and O&G are also measured at the offshore stations as potential indicators of wastewater. TSS was detected frequently at the offshore stations in 2009 at concentrations that varied considerably between 0.2 to 33.5 mg/L per sample (Table 3.5). In contrast, O&G was detected in only one sample at a concentration of 1.6 mg/L. Of the 284 seawater samples with elevated TSS concentrations (≥ 8.0 mg/L), 22 corresponded to samples with elevated FIBs, one of which met the FTR criteria for contamination. Conversely, 113 of these high TSS samples occurred at bottom depths; these high concentrations were likely due to the re-suspension of bottom sediments when the CTD touched the sea floor. The remaining 171 high TSS values were found in surface-water and mid-water samples, and tended to be associated either with the presence of phytoplankton blooms or runoff from storm activity that occurred around the time of sampling.

Table 3.5
Summary of total suspended solid (TSS) concentrations in samples collected from the SBOO offshore stations in 2009. Data include the number of detected values (*n*), as well as minimum (Min), maximum (Max), and mean detected concentrations for each month. The method detection limit = 1.6 mg/L for TSS.

	n	Min	Max	Mean
January	75	1.6	28.4	6.2
February	72	0.2	16.1	5.3
March	75	0.2	47.7	7.2
April	75	1.9	19.0	6.5
May	75	0.2	19.3	7.4
June	75	0.2	15.7	5.2
July	75	0.2	16.5	6.5
August	75	0.2	12.5	6.1
September	75	2.1	18.5	8.3
October	75	2.6	24.4	7.3
November	75	2.8	18.2	8.1
December	75	2.6	33.5	9.9

California Ocean Plan Compliance

Compliance with the 2001 COP water contact standards for samples collected from January through December 2009 at the SBOO shore stations located north of the USA/Mexico border and at the three offshore kelp bed stations is summarized in Appendix B.5. Overall, compliance in 2009 was similar to compliance in 2008 (see City of San Diego 2009) despite the decrease in rainfall this year (i.e., 5.5 inches in 2009 vs. 12.1 inches in 2008). During 2009, compliance along the shore ranged from 61 to 98% for the 30-day total coliform standard, 56 to 88% for the 60-day fecal coliform standard, and 75 to 100% for the 30-day fecal geometric mean standard. In addition, the shore station samples were out of compliance with the 10,000 total coliform standard 19 times during the year. Differences in compliance rates during the year generally reflected trends in elevated FIBs; i.e., compliance was lowest between January–March and December when rainfall was greatest, especially at stations closest to the Tijuana River (i.e., S5, S6, S11) and to the south (i.e., S4, S10) (see previous discussion).

Compliance rates for samples collected at the three kelp bed stations tended to be higher than at the shore stations, which reflects the lower levels of FIBs found in these samples. Compliance at these sites during 2009 ranged from 80 to 98% for the 30-day total coliform standard, 80 to 98% for the 60-day fecal coliform standard, and 100% for the 30-day fecal geometric mean standard. In addition, the kelp bed stations were never out of compliance with the 10,000 total coliform standard. As with the shore stations, the lowest compliance rates tended to occur during months with the most rain at stations I25 and I26 located nearest the Tijuana River.

Summary and Conclusions

There was no evidence that wastewater discharged to the ocean via the SBOO reached the shoreline or nearshore recreational waters in 2009. Although elevated FIB densities were detected along the shore, and occasionally at the kelp bed or other nearshore stations, these data likely do not indicate shoreward transport of the SBOO wastewater plume. Instead, analysis of FIB distributions and the results of satellite imagery data indicate that other sources such as outflows from the Tijuana River and Los Buenos Creek, as well as surface runoff associated with rainfall events are more likely to have impacted water quality along and near the shore in the South Bay region. For example, the shore stations located near the Tijuana River and Los Buenos Creek have historically had higher numbers of contaminated samples than stations located farther to the north. Further, long-term analyses of various water quality parameters have demonstrated that the general relationship between rainfall and elevated FIB levels has remained consistent since ocean monitoring began in 1995, including the period prior to wastewater discharge (e.g., see City of San Diego 2000). Finally, no indication of shoreward movement of the plume was evident in remote sensing images (see Svejkovsky 2010).

During 2009, the majority of elevated FIB densities not associated with rainfall events occurred at several offshore sites located within 1000 m of the SBOO diffusers at a depth of 18 m. Additionally, only two samples with elevated FIBs were collected near or at the surface during the year, although remote sensing observations did detect the signature of the wastewater plume in near-surface waters over the discharge site on several occasions during the winter. As discussed in the previous section, the low incidences of contaminated seawater at these times were most likely due to chlorination of IWTP effluent that typically occurs during the winter. In contrast, the lack of contaminated surface waters during the summer is expected due to wastefield entrapment beneath the thermocline.

Literature Cited

[APHA] American Public Health Association (1998). Standard Methods for the Examination of Water and Wastewater, 20th edition. A.E. Greenberg, L.S. Clesceri, and A.D. Eaton (eds.). American Public Health Association, American Water Works Association, and Water Pollution Control Federation.

Bordner, R., J. Winter, and P. Scarpino, eds. (1978). Microbiological Methods for Monitoring the Environment: Water and Wastes, EPA Research and Development, EPA-600/8-78-017.

[CDHS] California State Department of Health Services. (2000). Regulations for Public Beaches and Ocean Water-Contact Sports Areas. Appendix A: Assembly Bill 411, Statutes of 1997, Chapter 765. http://www.dhs.ca.gov/ps/ddwem/beaches/ab411_regulations.htm.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2008. City of San Diego

Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). EMTS Division Laboratory Quality Assurance Report, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Gersberg, R., J. Tiedge, D. Gottstein, S. Altmann, K. Watanabe, and V. Luderitz. (2008). Effects of the South Bay Ocean Outfall (SBOO) on beach water quality near the USA-Mexico border. International Journal of Environmental Health Research, 18:149–158.

Largier, J., L. Rasmussen, M. Carter, and C. Scearce. (2004). Consent Decree – Phase One Study Final Report. Evaluation of the South Bay International Wastewater Treatment Plant Receiving Water Quality Monitoring Program to determine its ability to identify source (s) of recorded bacterial exceedences. Scripps Institution of Oceanography, University of California, San Diego, CA.

Noble, R., S. Weisberg, M. Leecaster, C. McGee, J. Dorsey, P. Vainik, and V. Orozco-Borbón. (2003). Storm effects on regional beach water quality along the southern California shoreline. Journal of Water and Health, 1: 23–31.

Ocean Imaging. (2010). Ocean Imaging Corporation archive of aerial and satellite-derived images. http://www.oceani.com/SanDiegoWater/index.html.

Svejkovsky, J. (2008). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2007 – 31 December, 2007. Ocean Imaging, Solana Beach, CA.

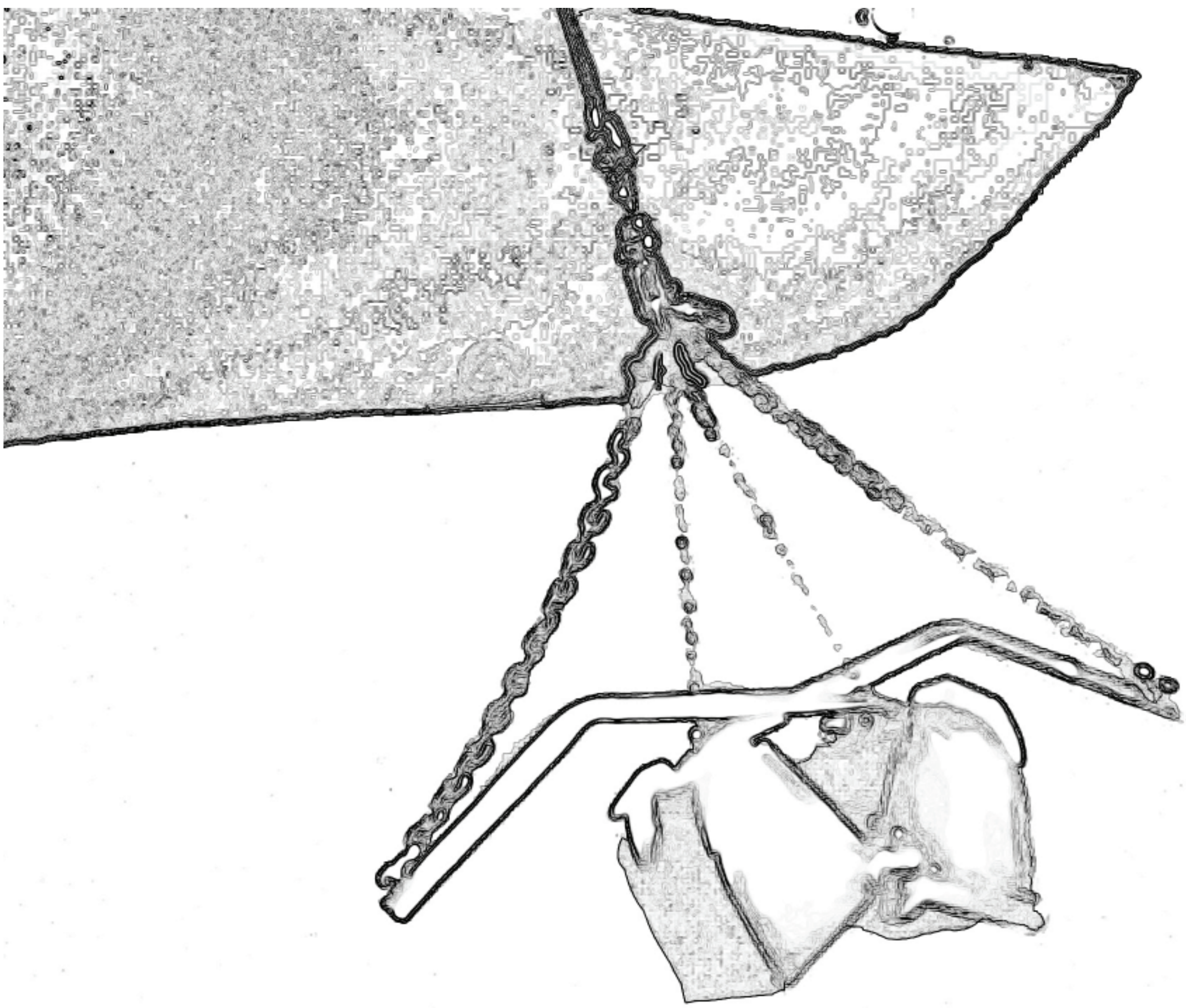
Svejkovsky, J. (2009). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2008 – 31 December, 2008. Ocean Imaging, Solana Beach, CA.

Svejkovsky, J. (2010). Satellite and Aerial Coastal Water Quality Monitoring in the San Diego/Tijuana Region: Annual Summary Report, 1 January, 2009 – 31 December, 2009. Ocean Imaging, Solana Beach, CA.

[SWRCB] California State Water Resources Control Board. (2001). California Ocean Plan, Water Quality Control Plan, Ocean Waters of California. California Environmental Protection Agency, Sacramento, CA.

Terrill, E., K. Sung Yong, L. Hazard, and M. Otero. (2009). IBWC/Surfrider – Consent Decree Final Report. Coastal Observations and Monitoring in South Bay San Diego. Scripps Institution of Oceanography, University of California, San Diego, CA.

Chapter 4
Sediment Characteristics



Chapter 4. Sediment Characteristics

INTRODUCTION

Ocean sediment samples are collected and analyzed as part of the South Bay Ocean Outfall (SBOO) monitoring program to characterize the surrounding physical environment and assess general sediment quality. The analysis of parameters such as sediment grain size and the relative percentages of both coarse (e.g., sand) and fine (e.g., silt and clay) fractions can provide useful information about current velocity, amount of wave action, and overall habitat stability. Further, understanding particle size distributions facilitates interpretation of the interactions between benthic organisms and the environment. For example, differences in sediment composition (e.g., fine vs. coarse particles) and associated levels of organic loading at specific sites can affect the burrowing, tube building, and feeding abilities of infaunal invertebrates, thus affecting benthic community structure (Gray 1981, Snelgrove and Butman 1994). Also, many demersal fish species are associated with specific sediment types that reflect the habitats of their preferred invertebrate prey (Cross and Allen 1993). Consequently, understanding the differences in sediment conditions and quality over time and space is crucial to assessing coincident changes in benthic invertebrate and demersal fish populations (see Chapters 5 and 6, respectively).

Both natural and anthropogenic factors affect the composition, stability and distribution of seafloor sediments. Natural factors that affect sediment conditions on the continental shelf include inputs from rivers and bays (e.g., outflows, tidal exchange), beach erosion, runoff from other terrestrial sources, decomposition of calcareous organisms, strength and direction of bottom currents, wave action, and seafloor topography (e.g., Emery 1960). Geological history can also affect the chemical composition of local sediments. For example, erosion from coastal cliffs and shores, and flushing of terrestrial sediments and debris from bays, rivers and streams can contribute to the deposition and accumulation of metals or other contaminants and also affect the overall organic content of sediments. Additionally, primary productivity by marine phytoplankton is a major source of organics to these sediments (Mann 1982, Parsons et al. 1990).

Municipal wastewater outfalls are one of many anthropogenic factors that can directly influence the composition and distribution of sediments through the discharge of treated effluent and the subsequent deposition of a wide variety of organic and inorganic compounds. Some of the most commonly detected compounds discharged via ocean outfalls are trace metals, pesticides, and various organic compounds such as organic carbon, nitrogen, and sulfides (Anderson et al. 1993). Moreover, the presence of large outfall pipes and associated ballast materials (e.g., rock, sand) may alter the hydrodynamic regime in surrounding areas.

This chapter presents summaries and analyses of sediment particle size and chemistry data collected during 2009 at monitoring sites surrounding the SBOO. The primary goals are to: (1) assess possible effects of wastewater discharge on benthic habitats by analyzing spatial and temporal variability of various sediment parameters, (2) determine the presence or absence of sedimentary and chemical footprints near the discharge site, and (3) evaluate overall sediment quality in the region.

Materials and Methods

Field Sampling

Sediment samples were collected at 27 benthic stations in the SBOO region during January and July 2009 (Figure 4.1). These stations range in depth from 18 to 60 m and are distributed along or adjacent to four main depth contours. Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the cast

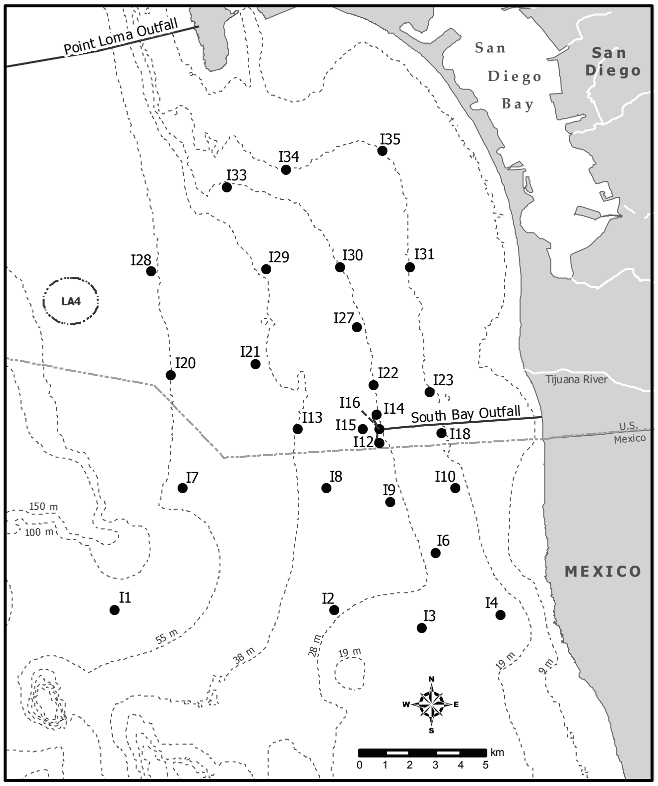


Figure 4.1
Benthic station locations sampled for the South Bay Ocean Outfall Monitoring Program.

was used for macrofaunal community analysis (see Chapter 5) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to EPA guidelines (U.S. EPA 1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. Sieves were used when a sample contained substantial amounts of coarse material (e.g., coarse sand, gravel, shell hash) which would damage the Horiba analyzer and/or where the general distribution of sediment sizes in the sample would be poorly represented by laser analysis. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm, and separate a seventh fraction of all particles finer than 0.063 mm. In 2009, three samples were processed by sieve analysis: I23 (January), I28 (July), and I34 (July). All other particle size analyses were performed on the Horiba analyzer, which measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Prior to laser analysis, coarser sediments were removed by screening the samples through a 2.0-mm mesh sieve; these data are expressed herein as the "coarse" fraction of the total sample sieved. Results from sieve analysis and output from the Horiba were categorized into sand, silt, and clay fractions as follows: sand was defined as particles ranging between 2.0 and >0.0625 mm in diameter, silt as particles between 0.0625 and >0.0039 mm, and clay as particles between 0.0039 and >0.00049 mm. These data were standardized and combined with any sieved coarse fraction (i.e., particles >2.0 mm) to obtain a distribution of coarse, sand, silt, and clay fractions totaling 100%. These four size fractions were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1968). These parameters were then summarized and expressed as overall mean particle size (mm), phi size (mean, standard deviation, skewness, kurtosis), and the proportion of coarse, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was analyzed for total organic carbon (TOC), total nitrogen (TN), total sulfides, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.1). TOC and TN were measured as percent weight (% wt) of the sediment sample; sulfides and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and expressed as parts per billion (ppb). The data for each parameter reported herein were generally limited to values above method detection limits (MDL). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry (i.e., spectral peaks confirmed). A detailed description of the analytical protocols is available in City of San Diego (2010).

Data Analyses

Data summaries for particle size and chemistry parameters included detection rates (i.e., number of reported values/number of samples), annual means of detected values for all stations combined (areal mean), and minimum, median, and maximum values during the year. Total PAH, total DDT, and total PCB were calculated for each sample as the sum of all constituents with reported values; values for each individual constituent are listed in Appendix C.2. Statistical analyses included Spearman Rank correlation of all sediment chemistry parameters with percent fines. This non-parametric analysis accommodates non-detects (i.e., analytes measured below MDLs) without the use of value-substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (see Conover 1980). Therefore, a criterion of < 50% non-detects was used to screen eligible constituents for this analysis. Results from the correlation analyses were confirmed by graphical analyses.

In addition, data from the 2009 surveys were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally calculated the ERLs and ERMs to provide a means for interpreting monitoring data. The ERLs are considered to represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Levels of contamination were further evaluated by comparing the current survey results with historical data, including comparisons between annual maximum values from 2009 to those from the pre-discharge period (1995–1998). In addition, data for percent fines and organic indicators from stations closest to the outfall (nearfield) were compared to all other stations (farfield) over the pre- and post-discharge periods. Stations considered "nearfield" (I12, I14, I15, I16) are located within 1000 m of the outfall wye.

Results and Discussion

Particle Size Distribution

Ocean sediments were diverse at the benthic sites sampled around the SBOO in 2009. Percent sands were generally the largest fraction with values ranging from 20.5% to 98.6%, whereas percent fines (silt and clay) ranged from 0% to 79.5% (Table 4.1). However, there were no clear patterns in grain-size distribution relative to the outfall (Figure 4.2). The diversity of sediment types within the region appears to reflect the different geological origins of various materials as it has for many years. For example, visual observations of the grab samples collected during the year revealed the presence of several unique types of coarse sediments, including red relict sands, black sands, and shell hash (see Appendix C.3). Overall, sediment composition has been highly variable throughout the South Bay region since sampling first began in 1995 (see City of San Diego 2000).

In contrast to the regional diversity described above, there has not been any substantial increase in fine sediments at stations near the outfall or throughout the region since wastewater discharge began in 1999 (see Figure 4.3). Additionally, sediment composition remained fairly stable at most stations during 2009. For example, intra-station particle size composition varied by less than 10% at most sites between the winter and summer surveys (see Appendix C.3). This general continuity between seasons in terms of percent fines is evident in Figure 4.3. The main exceptions to this pattern occurred at stations I16, I18, I23, I28 and I29. For example, sediments collected from station I16 in January contained the highest proportion of fines (79.5%), which

Table 4.1

Summary of particle size and sediment chemistry parameters at SBOO benthic stations during 2009. Data include the detection rate (DR), areal mean of detected values, and minimum (Min), median, and maximum (Max) values for the entire survey area. The maximum value from the pre-discharge period (i.e., 1995–1998) is also presented. ERL = effects range low threshold; ERM = effects range median threshold; na = not available; nd = not detected; SD = standard deviation; TN = total nitrogen; TOC = total organic carbon.

	2009 Summary*					Pre-discharge		
Parameter	DR (%)	Areal Mean	Min	Median	Max	Max	ERL	ERM
Particle Size								
Mean *(mm)*	**	0.26	0.02	0.13	0.66	0.76	na	na
Mean *(phi)*	**	2.4	0.6	3.0	5.7	4.2	na	na
SD *(phi)*	**	0.9	0.5	0.9	1.9	2.5	na	na
Coarse *(%)*	**	4.0	0.0	0.0	27.1	52.5	na	na
Sand *(%)*	**	83.8	20.5	88.6	98.6	100.0	na	na
Fines *(%)*	**	12.2	0.0	9.6	79.5	47.2	na	na
Organic Indicators								
Sulfides *(ppm)*	89	2.18	nd	0.81	25.30	222.00	na	na
TN *(% weight)*	98	0.024	nd	0.019	0.163	0.077	na	na
TOC *(% weight)*	100	0.346	0.030	0.183	5.460	0.638	na	na
Trace Metals (ppm)								
Aluminum	100	4932	741	4355	30100	15800	na	na
Antimony	31	0.4	nd	nd	0.9	5.6	na	na
Arsenic	100	2.76	0.36	1.82	11.90	10.90	8.2	70
Barium	100	25.17	1.99	20.70	177.00	54.30	na	na
Beryllium	44	0.09	nd	nd	0.33	2.14	na	na
Cadmium	48	0.10	nd	nd	0.42	0.41	1.2	9.6
Chromium	100	10.0	3.2	9.3	33.2	33.8	81	370
Copper	96	3.6	nd	3.0	37.6	11.1	34	270
Iron	100	6480	1300	6100	29300	17100	na	na
Lead	96	2.36	nd	1.77	20.00	6.80	46.7	218
Manganese	100	51.4	5.7	48.3	291.0	162.0	na	na
Mercury	50	0.010	nd	nd	0.063	0.078	0.15	0.71
Nickel	100	3.4	0.7	2.6	22.8	13.6	20.9	51.6
Selenium	0	—	nd	nd	nd	0.62	na	na
Silver	22	0.41	nd	nd	0.63	nd	1	3.7
Thallium	0	—	nd	nd	nd	17	na	na
Tin	76	0.7	nd	0.4	4.5	nd	na	na
Zinc	100	17.1	2.3	13.2	126.0	46.9	150	410
Pesticides (ppt)								
Total DDT	41	1084	nd	nd	9400	23380	1580	46100
HCB	24	261	nd	nd	700	nd	na	na
Total PCB (ppt)	44	523	nd	nd	970	na	na	na
Total PAH (ppb)	0	—	nd	nd	nd	636.5	4022	44792

* Minimum, maximum, and median values were calculated based on all samples ($n = 54$), whereas means were calculated on detected values only ($n \leq 54$).

** Particle size parameters calculated for all samples.

greatly exceeded the historical maximum of 17% for this site, as well as the entire South Bay region (i.e., 50%). The high proportion of fine sediments at I16 during the winter appears to have been an anomaly as it did not persist into summer when the site was characterized by only 8% fines. The higher proportions of fines at stations I18 and I28 also did not persist into the summer.

The sorting coefficient reflects the range of particle sizes comprising sediments and is calculated as the standard deviation (SD) in phi size units (see Table 4.1). In general, areas composed of particles of similar size are considered to have well-sorted sediments (i.e., SD≤0.5 phi) and are indicative of areas subject to fast moving currents or large disturbances (e.g., storm surge, rapid suspension/deposition of materials). In contrast, poorly sorted sediments (i.e., SD≥1.0 phi) typically indicate areas of low disturbance that often result in highly variable or patchy grain size distributions (Folk 1968). Sediments collected throughout the South Bay region, including at stations located near the outfall, tended to be moderately well to poorly sorted, with average sorting coefficients ranging from 0.5 to 1.9. The highest sorting coefficients for 2009 (~1.9) occurred at stations I16, I18, and I28 in the January survey (Appendix C.3).

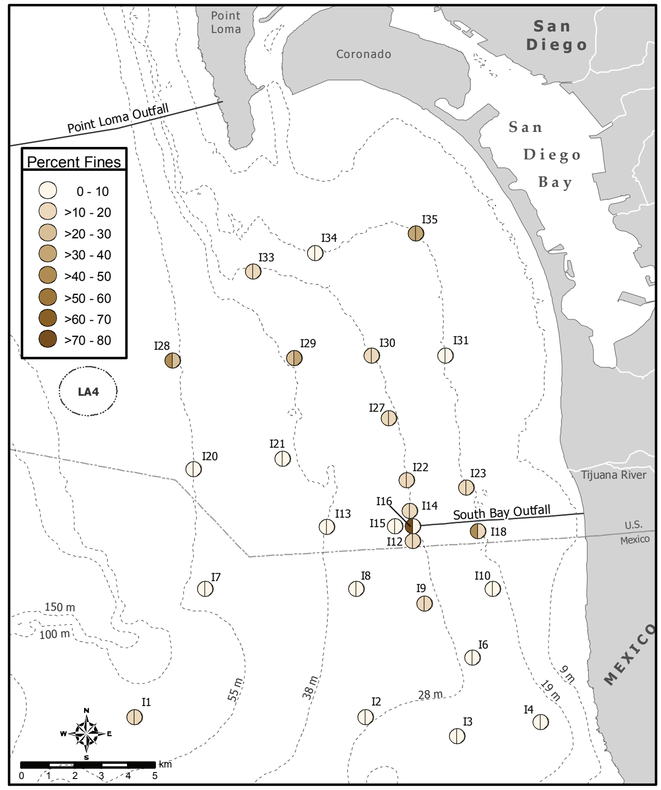


Figure 4.2
Distribution of fine sediments (percent fines) at SBOO benthic stations sampled during 2009. Split circles show results of January (left) and July (right) surveys.

Indicators of Organic Loading

Total organic carbon (TOC), total nitrogen (TN), and sulfides are quantified in sediments at stations surrounding the SBOO as measures of organic loading. Organic materials may be deposited in marine habitats via various pathways and originating from both anthropogenic (e.g., wastewater and stormwater discharges, urban runoff) and natural (e.g., primary productivity and breakdown of detrital materials) sources (Eganhouse and Venkatesan 1993). Consequently, organic enrichment is of concern because it may impair habitat quality for benthic marine organisms and thus disrupt ecological processes. For example, sulfides, which are the by-products of the anaerobic breakdown of organic matter, can be toxic to benthic species if the sediments become excessively enriched (Gray 1981). Additionally, nitrogen enrichment can lead to sudden phytoplankton "blooms" in coastal waters. After such blooms occur, a flux of organic material may again be deposited in the benthos as planktonic organisms die and settle to the seafloor.

There was no evidence of organic enrichment that could be associated with wastewater discharge in South Bay sediments during 2009. Although detection rates for TOC, TN and sulfides were high (i.e., ≥89%; see Table 4.1), median concentrations of these organic indicators were similar to values found between 1995–1998 prior to the onset of discharge (Figure 4.3). Further, concentrations of these indicators co-varied with the proportion of fine sediments in each sample (Table 4.2) instead of proximity to the outfall. TN was found to be correlated the tighest with percent fines (Figure 4.4A), followed by TOC and then sulfides. Because of this relationship, values for each organic indicator varied widely across the region. TOC ranged from 0.03 to 5.46% wt, TN ranged from 0.008 to 0.163% wt, and sulfides ranged from 0.2 to 25.3 ppm (Table 4.1). The highest TN and sulfide concentrations occurred at station I16 in January, as did the second highest concentration of TOC (see Appendix C.4). In fact, this was the highest TN concentration reported since monitoring began in 1995. However, levels of all three indicators at the other outfall stations, as well as at I16 during the following July survey, were within the range of values reported elsewhere in the region.

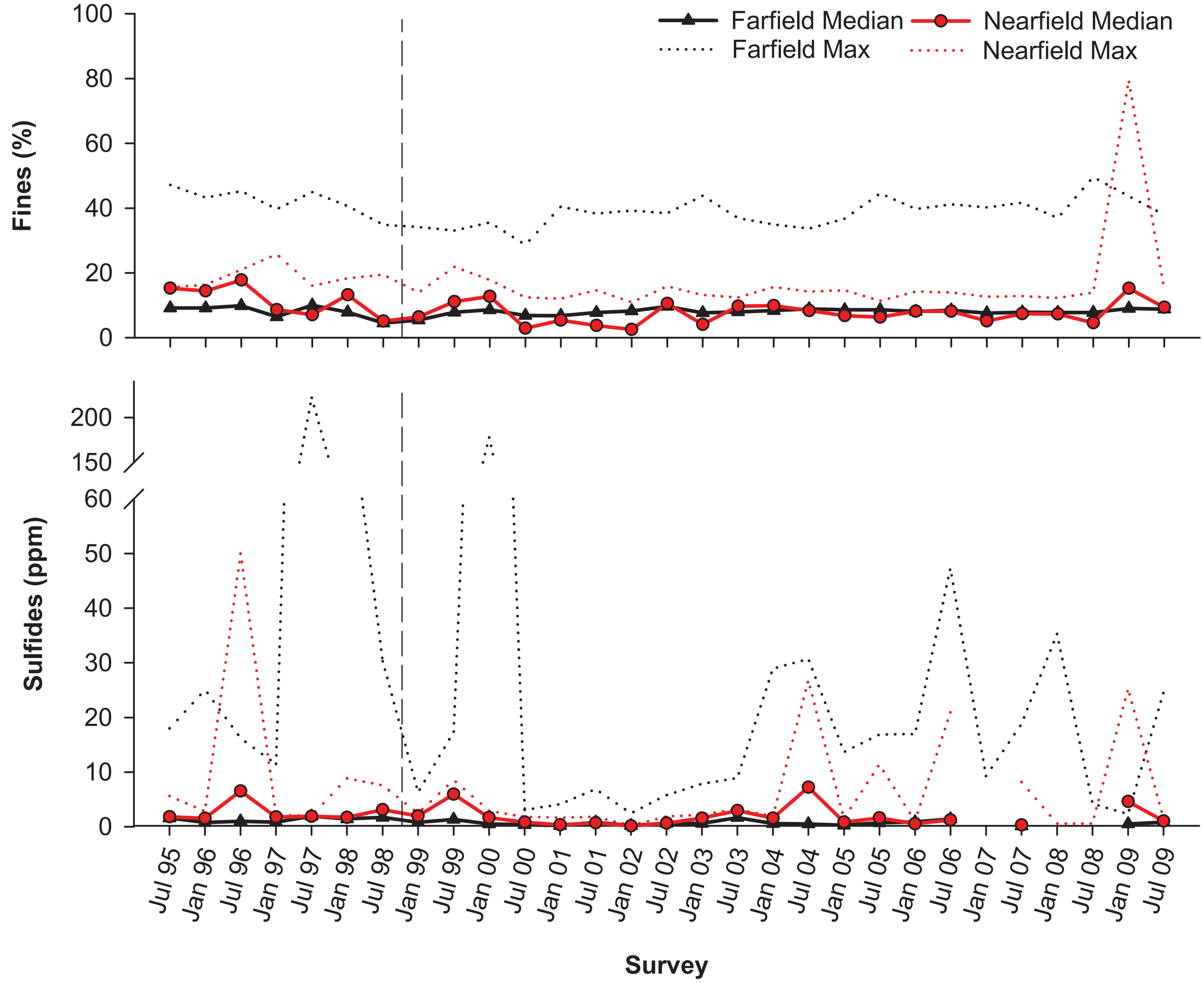


Figure 4.3
Summary of particle size and organic indicator data surrounding the SBOO from 1995 to 2009: Percent fines (Fines); Sulfides; Total Nitrogen (TN); Total Organic Carbon (TOC). Data are expressed as median and maximum values pooled over all farfield ($n=23$) and nearfield ($n=4$) stations. Breaks in data represent surveys where the median or maximum value was below detection limits. Dashed lines indicate onset of discharge from the SBOO.

Trace Metals

Aluminum, arsenic, barium, chromium, iron, manganese, nickel and zinc were detected in all sediment samples collected in the SBOO region during 2009 (Table 4.1). Antimony, beryllium, cadmium, copper, lead, mercury, silver and tin were detected less frequently at rates of 22–96%, while selenium and thallium were not detected at all. Concentrations were highly variable for each of the 16 trace metals detected, with no discernable patterns evident relative to the outfall (see Appendix C.5). Instead, the concentrations for several metals were correlated with the proportion of fine particles in the samples (Table 4.2). For example, manganese was found to have the highest correlation with percent fines (Figure 4.4B), followed next by aluminum, nickel, barium and zinc. Each of these five metals had correlation coefficients >0.85. Overall, most samples collected during 2009 had metal concentrations that were within the range of values reported prior to discharge. Exceptions that occurred throughout the region included samples from stations I16, I18, I21, I29 and I33. For example, the winter sample from station I16, which was characterized by unusually fine sediments (see discussion above), had the highest concentrations of aluminum, barium, iron, lead, nickel and tin ever reported, including the period prior to discharge. Other metals in this sample that were

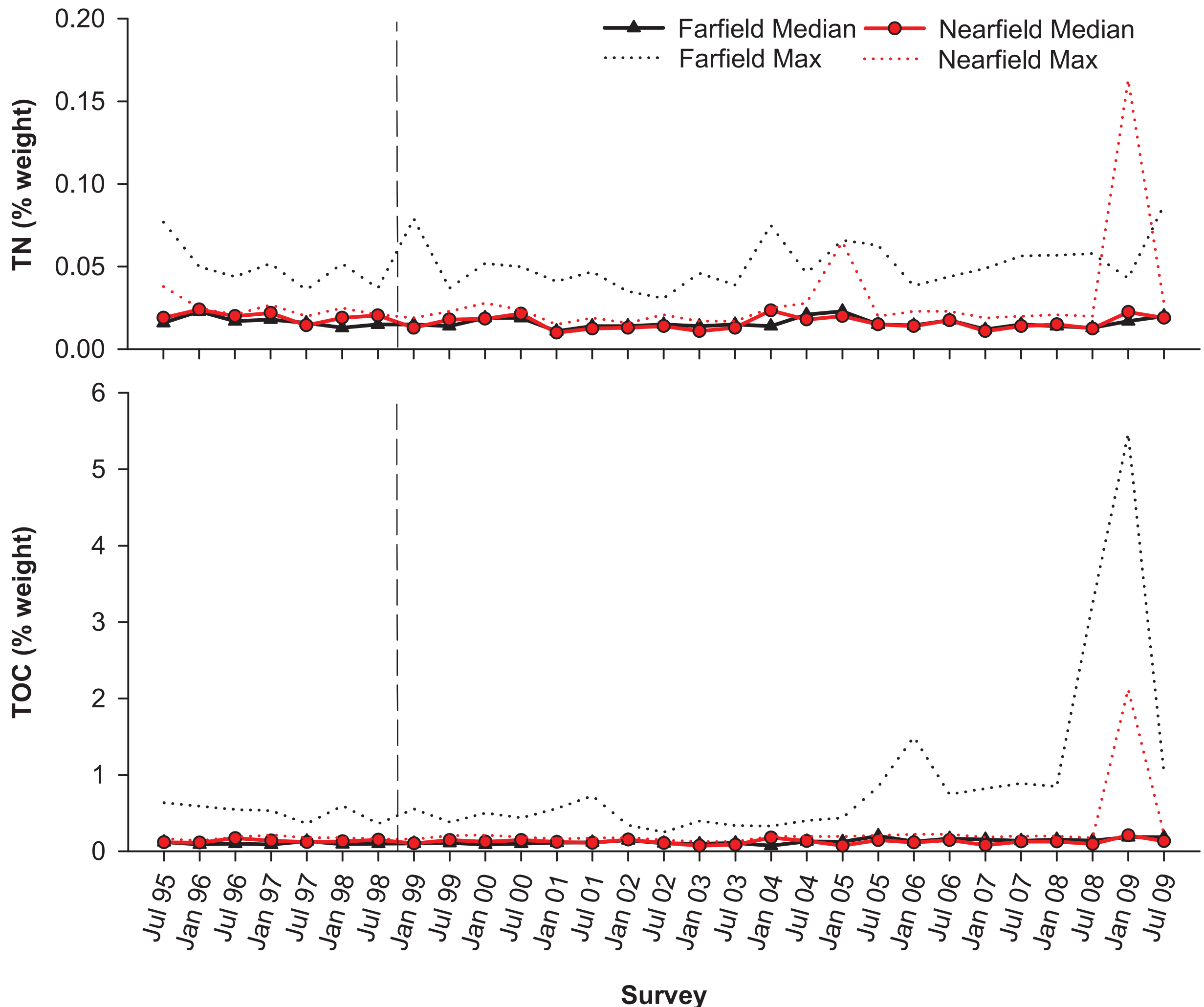


Figure 4.3 *continued*

detected at levels higher than pre-discharge values included arsenic, cadmium, copper, manganese and zinc. The summer sample from station I29 also had relatively high percent fines, as well as levels of aluminum, barium, copper, iron, manganese and zinc that were higher than pre-discharge concentrations. In contrast, the sediment samples from stations I18, I21 and I33 each contained only a single metal that exceeded concentrations reported before discharge began (i.e., barium at I18, arsenic at I21, nickel at I33). Despite these relatively high values, only three metals exceeded environmental threshold values during the year. These included the ERL for arsenic from station I21 located northwest of the discharge site during both January and July, and the ERLs for copper and nickel in the station I16 January sample as described above. No samples collected during 2009 had metal concentrations that exceeded ERM thresholds.

Pesticides

Chlorinated pesticides were detected in up to 41% of the South Bay sediment samples collected in 2009 (Table 4.1, Appendix C.6). Total DDT (primarily p,p-DDE) was the most prevalent pesticide, occurring in sediments from 14 of 27 stations at concentrations ranging between 95–9400 ppt. The ERL for this pesticide was exceeded in only three samples in 2009, including one sample from station I16 (January) and two samples from station I29 (January and July). However, all DDT concentrations were lower than maximum values reported during the pre-discharge period. Another pesticide, hexachlorobenzene (HCB), was detected in 24% of samples, at a total of 12 stations, with values ranging from 77 to 700 ppt. As with the various trace metals, pesticide concentrations showed no patterns relative to wastewater discharge.

Table 4.2

Results of Spearman Rank correlation analyses of percent fines and all other sediment chemistry parameters from samples collected in the SBOO region in 2009. Shown are analytes which had correlation coefficients (r_s) ≥ 0.60. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 4.4 below.

Analyte	r_s
Organic Indicators	
Sulfides *(ppm)*	0.68
Total Nitrogen *(% weight)*	0.89
Total Organic Carbon *(% weight)*	0.81
Trace Metals (ppm)	
Aluminum	0.90
Barium	0.88
Chromium	0.63
Copper	0.81
Iron	0.65
Manganese	0.91
Nickel	0.89
Zinc	0.86

PAHs and PCBs

PAHs were not detected in sediment samples collected during 2009. In contrast, 44% of the samples collected in 2009 had detectable levels of PCBs (compared to 9% in 2008), with concentrations ranging from 33 to 970 ppt (Table 4.1). PCBs were found in sediments from most SBOO stations in January 2009, but at only a single station in July (Appendix C.6). Total PCB concentrations at nearfield stations I12, I14, I15, I16 fell well within those reported elsewhere in the region (i.e., 360–840 ppt versus 330–970 ppt). The highest PCB concentration of the year was detected in January in sediment from I10, located south of the United States/Mexico border.

Summary and Conclusions

Sediment composition in the South Bay outfall region was diverse in 2009, with grain size

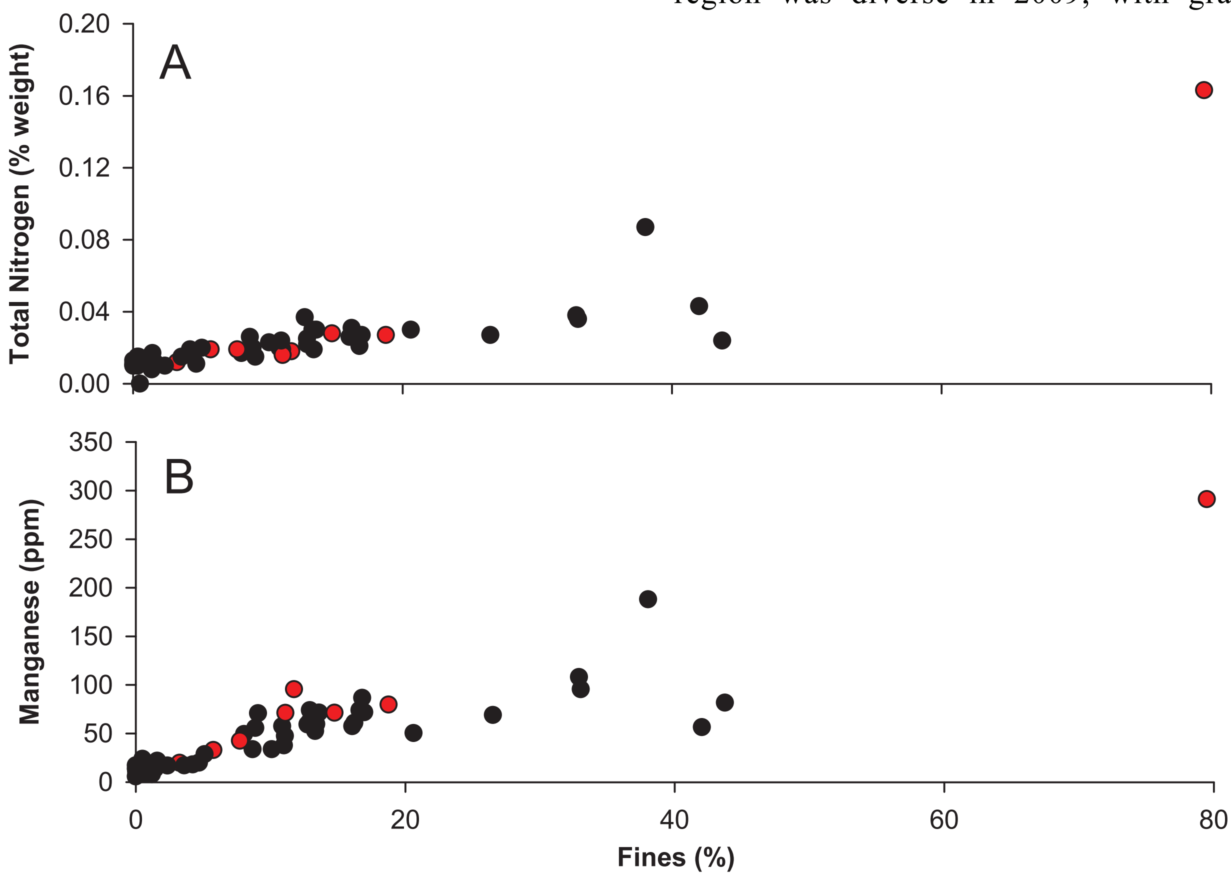


Figure 4.4

Scatterplot of percent fines and concentration of total nitrogen (A) and manganese (B) in SBOO sediments in 2009. Samples collected from nearfield stations are indicated in red.

distributions ranging from very fine to very coarse particles. The diversity of sediment types may be partially attributed to the multiple geological origins of red relict sands, shell hash, coarse sands, and other detrital materials that occur in the offshore area surrounding the SBOO (Emery 1960). In addition, sediment deposition associated with the transport of materials originating from the Tijuana River, and to a lesser extent from San Diego Bay, may contribute to the higher silt content at some stations located near the outfall, as well as to the north (see City of San Diego 1988). For example, in late December 2008 there was evidence of a large influx of fine sediments from coastal rivers (particularly the Tijuana River) with heavy winter rains, and subsequent re-suspension of these sediments by wave and surge action (J. Warrick, pers. comm., City of San Diego 2009). This may have contributed to the spikes in fine particles at several stations, particularly I16, I18, and I28 in January 2009, although it is unclear why the pattern was not more widespread throughout the region. Regardless, the high sorting coefficients of sediments in these samples, the lack of similar sediment conditions at nearby stations, or at I16, I18, and I28 during the following July survey, suggested these conditions occurred over a relatively small spatial (and possibly temporal) scale. There was no evident relationship between sediment grain size composition and proximity to the outfall discharge site.

Various trace metals, indicators of organic loading, chlorinated pesticides, and PCBs were detected in sediment samples collected from SBOO benthic stations during 2009. Concentrations of these contaminants were highly variable, and several were detected at relatively high levels for the region (i.e., higher than pre-discharge values) particularly in the January sample from station I16. Despite these relatively high values, concentrations remained relatively low compared to many other coastal areas off southern California such as Los Angeles (see Schiff and Gossett 1998, Noblet et al. 2003, Schiff et al. 2006, Maruya and Schiff 2009) and only three metals (arsenic, copper, nickel) and the pesticide DDT exceeded biological threshold values for southern California.

Overall, sediments in the South Bay region were similar in 2009 to years past (see City of San Diego 2007, 2008, 2009) and there was no evidence of contamination by the discharge of wastewater from the SBOO. Although there were some samples where constituent concentrations exceeded pre-discharge maximums, most samples had contaminant concentrations that were not substantially different from those detected before discharge began in early 1999 (see City of San Diego 2000). In addition, the samples that did exceed pre-discharge values and/or biological thresholds were collected from stations widely distributed throughout the region and showed no patterns that could be attributed to wastewater discharge. Instead, concentrations of TOC, TN, sulfides, and several metals tended to be higher at sites characterized by finer sediments. This pattern is consistent with that found in other studies, in which the accumulation of fine particles has been shown to greatly influence the organic and metal content of sediments (e.g., Eganhouse and Venkatesan 1993).

Literature Cited

Anderson, J.W., D.J. Reish, R.B. Spies, M.E. Brady, and E.W. Segelhorst. (1993). Human Impacts. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

City of San Diego. (1988). Tijuana Oceanographic Engineering Study, Vol I: Ocean Measurement Program. Prepared by Engineering Science for the City of San Diego.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). 2009 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2ed. John Wiley & Sons, Inc., New York, NY.

Cross, J.N. and L.G. Allen. (1993). Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eganhouse, R.P. and M.I. Venkatesan. (1993). Chemical Oceanography and Geochemistry. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 71–189.

Emery, K.O. (1960). The Sea Off Southern California. John Wiley, New York, NY.

Folk, R.L. (1968). Petrology of Sedimentary Rocks. Hemphill, Austin, TX.

Gray, J.S. (1981). The Ecology of Marine Sediments: An Introduction to the Structure and Function of Benthic Communities. Cambridge University Press, Cambridge, England.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Mann, K.H. (1982). The Ecology of Coastal Marine Waters: A Systems Approach. University of California Press, Berkeley, CA.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. In: H.J. Lee and W.R. Normark (eds.). Earth Science in the Urban Ocean: The Southern California Continental Borderland: Geological Society of America Special Paper 454. p 399–412.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern

California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parsons, T.R., M. Takahashi, and B. Hargrave. (1990). Biological Oceanographic Processes 3rd Edition. Pergamon Press, Oxford.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: Volume III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Snelgrove, P.V.R. and C.A. Butman. (1994). Animal-sediment relationships revisited: cause versus effect. Oceanography and Marine Biology Annual Review, 32: 111–177.

[U.S. EPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuary Protection.

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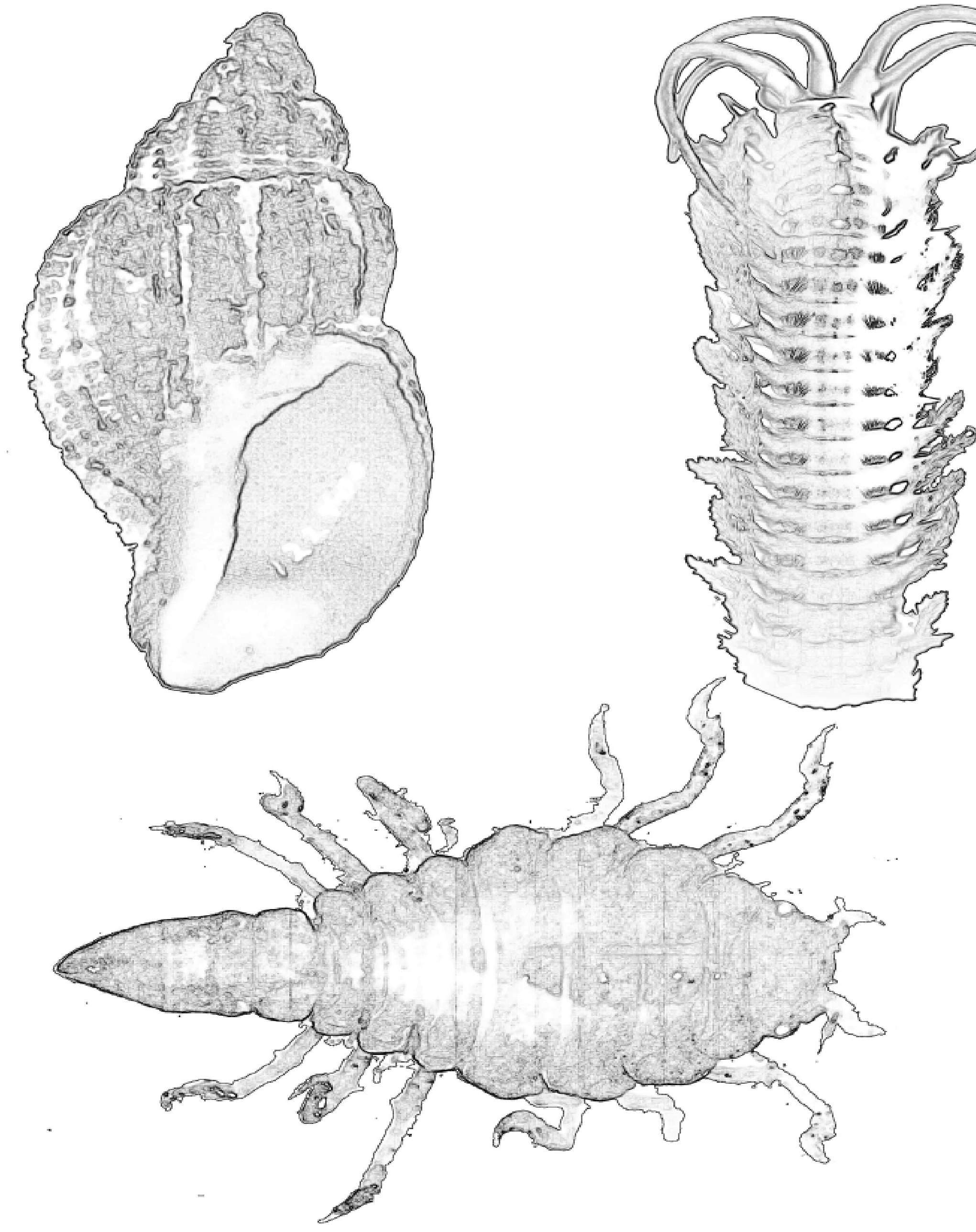
Chapter 5
Macrobenthic Communities



Chapter 5. Macrobenthic Communities

INTRODUCTION

Benthic macroinvertebrates along the coastal shelf of southern California represent a diverse faunal community that is important to the marine ecosystem (Fauchald and Jones 1979, Thompson et al. 1993a, Bergen et al. 2001). These animals serve vital ecological functions in wide ranging capacities (Snelgrove et al. 1997). For example, some species decompose organic material as a crucial step in nutrient cycling; other species filter suspended particles from the water column, thus affecting water clarity. Many species of benthic macrofauna also are essential prey for fish and other organisms.

Human activities that impact the benthos can sometimes result in toxic contamination, oxygen depletion, nutrient loading, or other forms of environmental degradation. Certain macrofaunal species are sensitive to such changes and rarely occur in impacted areas, while others are opportunistic and can persist under altered conditions (Gray 1979). Because various species respond differently to environmental stress, monitoring macrobenthic assemblages can help to identify anthropogenic impact (Pearson and Rosenberg 1978, Bilyard 1987, Warwick 1993, Smith et al. 2001). Also, since many animals in these assemblages are relatively stationary and long-lived, they can integrate the effects of local environmental stressors (e.g., pollution or disturbance) over time (Hartley 1982, Bilyard 1987). Consequently, the assessment of benthic community structure is a major component of many marine monitoring programs, which are often designed to document both existing conditions and trends over time.

Overall, the structure of benthic communities may be influenced by many factors including depth, sediment composition and quality (e.g., grain size distribution, contaminant concentrations), oceanographic conditions (e.g., temperature, salinity, dissolved oxygen, ocean currents), and biological factors (e.g., food availability, competition, predation). For example, benthic assemblages on the coastal shelf of southern California typically vary along sediment particle size and/or depth gradients (Bergen et al. 2001). Therefore, in order to determine whether changes in community structure are related to human impacts, it is necessary to have an understanding of background or reference conditions for an area. Such information is available for the monitoring area surrounding the South Bay Ocean Outfall (SBOO) and the San Diego region in general (e.g., City of San Diego 1999, 2000; Ranasinghe et al. 2003, 2007).

This chapter presents analyses and interpretation of the macrofaunal data collected at fixed stations surrounding the SBOO during 2009. Descriptions and comparisons of the different macrofaunal assemblages that inhabit soft bottom habitats in the region and analysis of benthic community structure are included.

Materials and Methods

Collection and Processing of Samples

Benthic samples were collected during January and July 2009 at 27 stations surrounding the SBOO located along the 19, 28, 38, or 55-m depth contours (Figure 5.1). Four stations considered to represent "nearfield" conditions herein (i.e., I12, I14, I15, I16) are located between 35 and 600 m of the outfall wye or diffuser legs.

Samples for benthic community analyses were collected from two replicate 0.1-m^2 Van Veen grabs per station during each survey. An additional grab was collected at each station for sediment quality analysis (see Chapter 4). The criteria to ensure consistency of grab samples established by the United States Environmental Protection Agency (U.S. EPA) were followed with regard to sample disturbance and depth of penetration (U.S. EPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen. Organisms retained on the screen were collected and

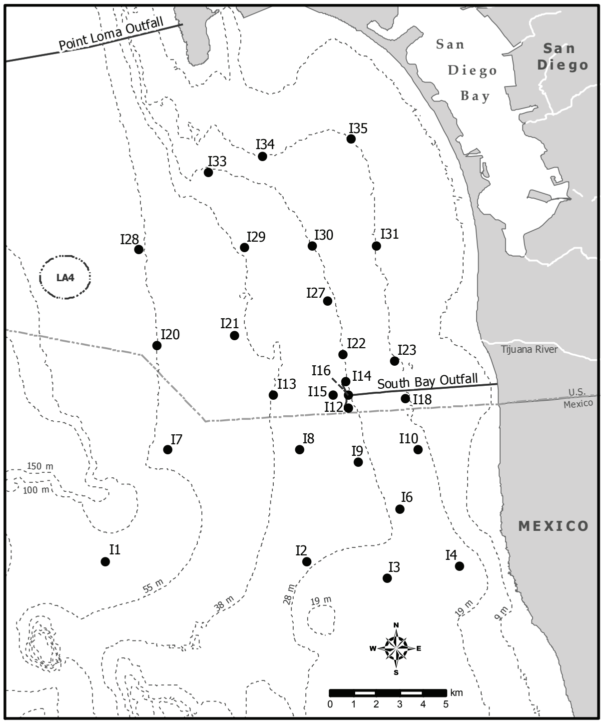


Figure 5.1
Benthic station locations sampled for the South Bay Ocean Outfall Monitoring Program.

relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the debris into major taxonomic groups by a subcontractor and then identified to species or the lowest taxon possible and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of species), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (Swartz et al. 1986, Ferraro et al. 1994), and the benthic response index (BRI; Smith et al. 2001). Additionally, the total or cumulative number of species over all grabs was calculated for each station.

Multivariate analyses were performed using PRIMER software to examine spatio-temporal patterns in the overall similarity of benthic assemblages (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (MDS). The macrofaunal abundance data were square-root transformed and the Bray-Curtis measure of similarity was used as the basis for classification. Similarity profile (SIMPROF) analysis was used to confirm non-random structure of the dendrogram (Clarke et al. 2008). Similarity percentages (SIMPER) analysis was used to identify individual species that typified each cluster group. Patterns in the distribution of macrofaunal assemblages were compared to environmental variables by overlaying the physico-chemical data onto MDS plots based on the biotic data (Field et al. 1982, Clarke and Ainsworth 1993).

Results and Discussion

Community Parameters

Species richness
A total of 762 macrobenthic taxa (mostly species) were identified during the 2009 SBOO surveys. Of these, approximately 23% ($n = 178$) represented rare taxa that were recorded only once. Mean values of species richness ranged from 37 taxa per 0.1 m^2 at station I18 to 129 taxa per 0.1 m^2 at station I28 (Table 5.1). Average values for the other 25 stations ranged from 47–120 taxa per 0.1 m^2. This wide variation in species richness is consistent with patterns seen in previous years, and can probably be attributed to the presence of different habitat or microhabitat types in the region (see City of San Diego 2006–2009). Higher numbers of species, for example, have typically occurred at stations such as I28 and I29 (e.g., City of San Diego 2009). However, overall species richness remained similar to last year, averaging only 1% higher in 2009 versus 2008. Although species richness varied spatially, there were no apparent patterns relative to distance from the outfall (Figure 5.2A).

Macrofaunal abundance
A total of 38,259 macrofaunal individuals were counted in 2009 with mean abundance values ranging

Table 5.1

Summary of macrobenthic community parameters for SBOO stations sampled during 2009. SR = species richness (no. species/0.1 m^2); Tot Spp = cumulative no. species for the year; Abun = abundance (no. individuals/0.1 m^2); H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index. Data are expressed as annual means ($n = 4$) except Tot Spp ($n = 1$).

Station	SR	Tot Spp	Abun	H'	J'	Dom	BRI
19-m Stations							
I35	90	174	434	3.5	0.79	25	31
I34	54	147	405	2.4	0.60	7	14
I31	63	133	235	3.3	0.80	21	20
I23	78	203	375	3.5	0.82	22	21
I18	37	93	144	2.7	0.82	11	20
I10	52	115	162	3.3	0.83	17	21
I4	51	141	199	3.1	0.80	16	10
28-m Stations							
I33	114	232	577	3.7	0.78	29	27
I30	69	150	239	3.7	0.87	26	25
I27	75	157	263	3.6	0.85	25	22
I22	104	224	462	3.7	0.79	27	23
I14	86	179	334	3.6	0.81	26	23
I16	71	179	296	3.3	0.81	23	27
I15	92	200	757	2.6	0.59	12	21
I12	107	219	467	3.7	0.79	29	22
I9	106	208	491	3.8	0.82	29	24
I6	63	139	496	2.6	0.63	10	15
I2	47	102	335	2.1	0.55	6	19
I3	50	116	358	2.4	0.62	9	15
38-m Stations							
I29	120	271	496	3.9	0.83	36	17
I21	60	131	263	3.3	0.81	17	6
I13	62	140	369	2.8	0.69	11	9
I8	61	132	431	2.7	0.65	11	18
55-m Stations							
I28	129	255	372	4.4	0.91	50	15
I20	59	142	186	3.3	0.82	21	6
I7	60	136	160	3.7	0.90	26	2
I1	74	170	263	3.5	0.83	24	13
Mean	75	112	354	3.3	0.77	21	18
Standard Error	3	4	19	0.1	0.01	1	1
Minimum	15	26	18	1.4	0.36	1	-1
Maximum	153	199	1415	4.6	0.97	59	36

from 144 to 757 animals per 0.1 m^2 sample (Table 5.1). The greatest number of animals occurred at station I15, which averaged 757 individuals per sample. In contrast, the fewest number of animals occurred at station I18 (144/0.1 m^2). Overall, there was a 15% decrease in total macrofaunal abundance between 2008 and 2009 (Figure 5.2B), with the greatest change occurring at station I6 (City of San Diego 2009).

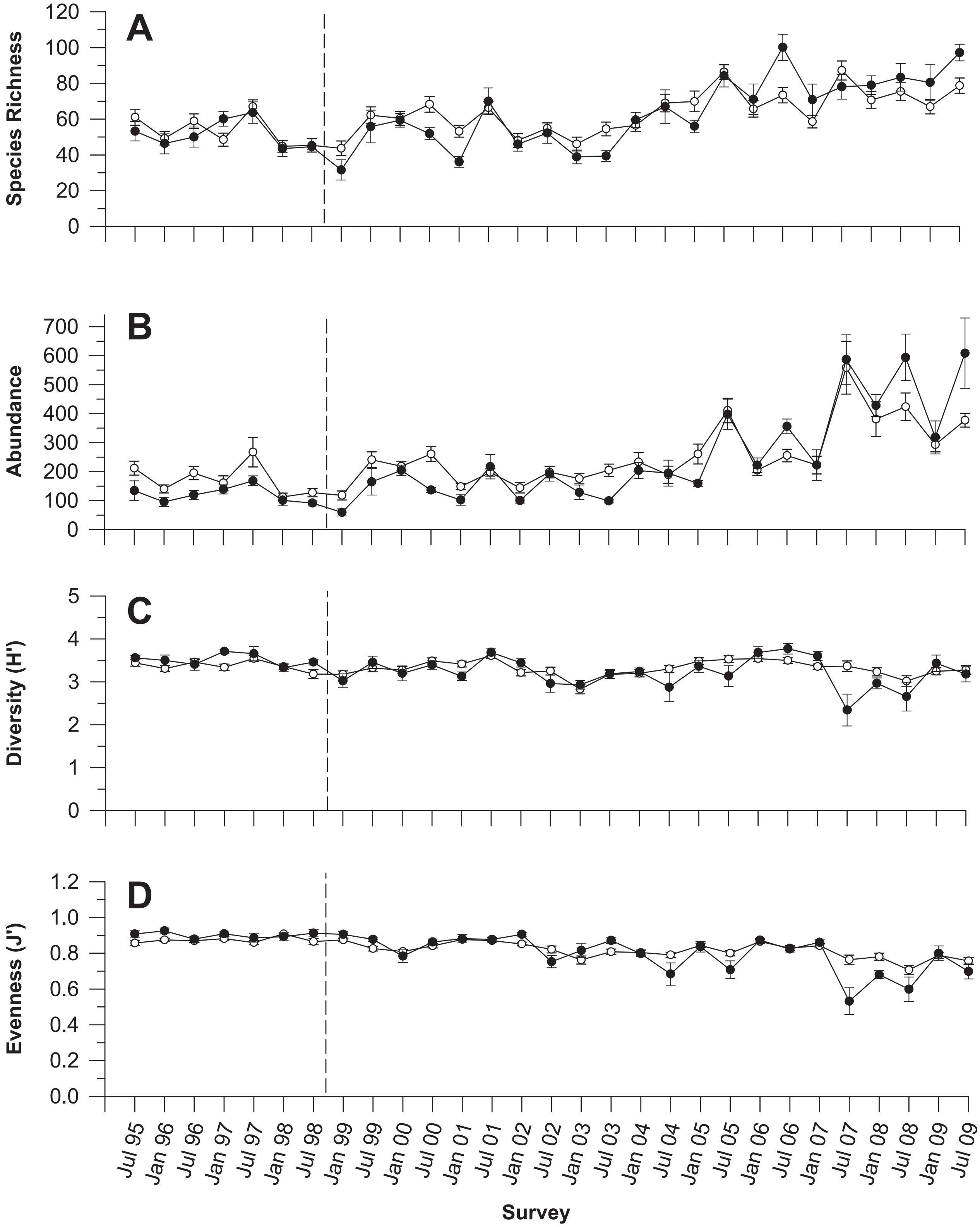


Figure 5.2

Summary of benthic community structure parameters surrounding the South Bay Ocean Outfall from 1995–2009: Species richness (no. of taxa); Abundance (no. of animals); Diversity = Shannon diversity index (H'); Evenness = Pielou's evenness index (J'); Swartz dominance index; BRI = Benthic response index. Data are expressed as means ± standard error per 0.1 m^2 pooled over nearfield stations (dark circles, $n = 8$) versus farfield stations (open circles, $n = 46$) for each survey. Dashed line indicates onset of discharge from the SBOO.

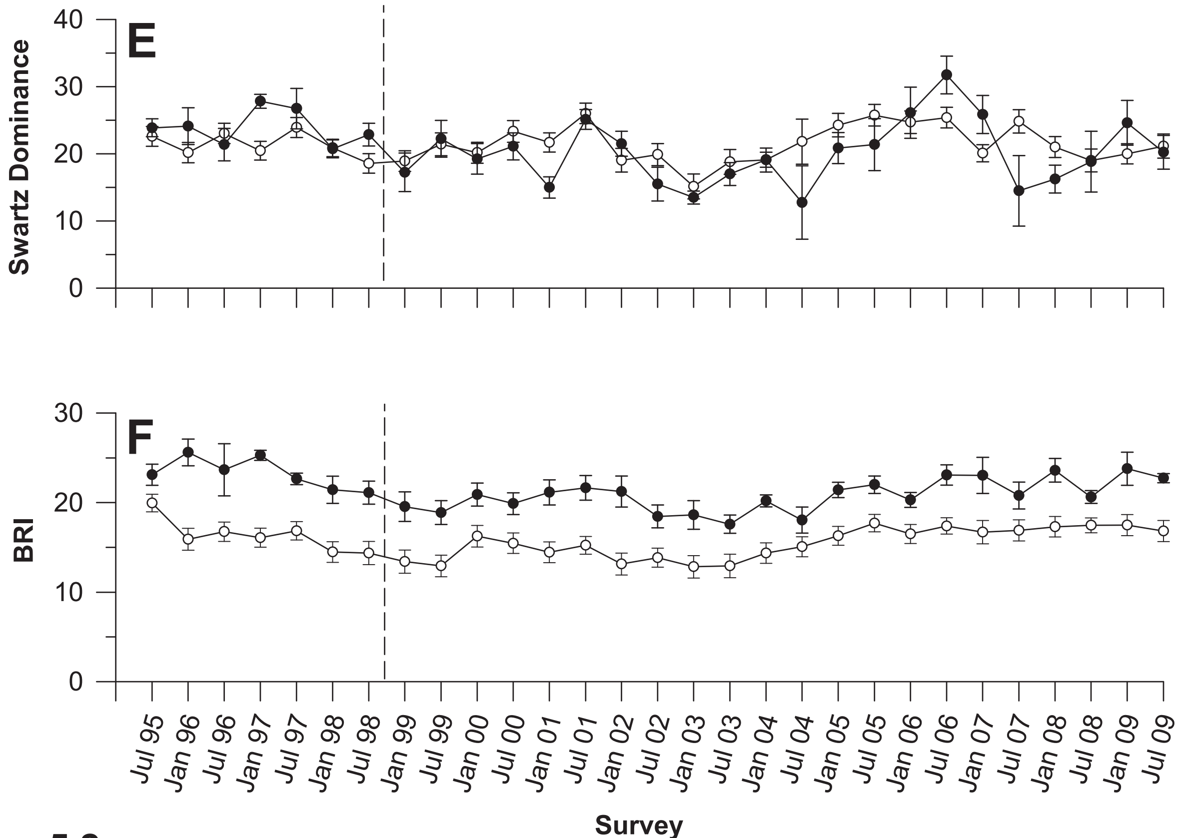


Figure 5.2 *continued*

Species diversity and dominance

Species diversity (H') averaged from 2.1 to 4.4 during 2009 (Table 5.1). Average diversity values in the region were generally similar to previous years, and there were no apparent patterns relative to distance from the outfall discharge site (Figure 5.2C). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed (i.e., not dominated by a few highly abundant species). During 2009, J' values averaged between 0.55 and 0.91 with spatial patterns similar to those for diversity.

Dominance was expressed as the Swartz dominance index, which is calculated as the minimum number of taxa whose combined abundance accounts for 75% of the individuals in a sample (Swartz et al. 1986, Ferraro et al. 1994). Therefore, lower index values (i.e., fewer taxa) indicate higher numerical dominance. Values at the individual SBOO stations averaged between 6 and 50 species per station during the year (Table 5.1). This range reflects the dominance of a few species at some sites (e.g., stations I2, I3, I34) versus other stations where many taxa contributed to the overall abundance (e.g., I28, I29). Overall, Swartz dominance values for 2009 were similar to historical values with no clear patterns evident relative to the outfall (Figure 5.2E).

Benthic Response Index

Benthic response index (BRI) values averaged from 2 to 31 at the various SBOO stations in 2009 (Table 5.1). Index values below 25 (on a scale of 100) are considered indicative of reference conditions, while those between 25 and 34 represent "a minor deviation from reference conditions" that should be confirmed by additional sampling (Smith et al. 2001). Stations I16, I33, and I35 were the only stations with mean BRI values above 25 (i.e., 27, 27, and 31, respectively), although there was no gradient relative to distance from the outfall. The index value for one grab sample collected at I16 (~40 m from the outfall wye) in January did appear to deviate from reference conditions (i.e., BRI = 36). A BRI value of 36 may begin to reflect a reduction or loss in biodiversity. Although the cause of this higher than normal BRI value is not clear, results of sediment analyses indicated that the sample was characterized by unusually fine sediments (i.e., 80% fines), as well as some elevated trace metals and organic indicator values (see Chapter 4). Additionally, the subsequent July sediment analyses showed no deviation from historical means.

Since monitoring first began in July 1995, mean BRI values at the four nearfield stations (I12, I14, I15, I16) have been higher than values for the farfield stations combined (Figure 5.2F). This pattern has remained consistent over time, including the period prior to January of 1999 when wastewater discharge was initiated through the SBOO. The difference is likely due to the effects of lower BRI values at the 38-m and 55-m stations on the farfield mean BRI (see Smith et al. 2001 for a discussion of the influence of depth on the BRI).

Dominant Species

Macrofaunal communities in the SBOO region were dominated by polychaete worms in 2009, accounting for 50% of all species collected (Table 5.2). Crustaceans accounted for 21% of the species, molluscs 15%, echinoderms 6%, and all other taxa combined for the remaining 8%. Polychaetes were also the most numerous animals, accounting for 73% of the total abundance. Crustaceans accounted for 12% of the animals, molluscs 8%, echinoderms 4%, and the remaining phyla 3%. Overall, the above distributions were very similar to those observed in 2008 (see City of San Diego 2009).

Eight polychaetes, one crustacean, and one echinoderm were among the 10 most abundant macroinvertebrates sampled during the year (Table 5.3). The most abundant species collected was the spionid polychaete *Spiophanes norrisi* (reported as *S. bombyx* in previous reports), which occurred at 100% of the stations and averaged 88 (2–930) individuals per sample. While *S. norrisi* was ubiquitous in the SBOO region, abundances at individual stations varied considerably. For example, two stations (I15 and I6 in July) had much higher abundances of this species than the other sites, with a combined total of 2594 individuals. Overall, *S. norrisi* accounted for about 25% (i.e., 9520 individuals) of the macrobenthic fauna sampled during 2009 (see Figure 5.3).

Few other macrobenthic species were as widely distributed as *S. norrisi* (Table 5.3), with only eight taxa occurring in 80% or more of the samples. Five of the most frequently collected species also were among the top 10 most abundant taxa (i.e., *Spiophanes norrisi*, Euclymeninae sp A, *Spiophanes duplex*, *Mediomastus* sp, *Ampelisca cristata cristata*). In contrast, the amphinomid polychaete *Pareurythoe californica* was found in relatively high numbers at only two stations, I23 and I34 where sediments were comprised almost entirely of sand and coarse materials (i.e., shell hash).

Table 5.2
The percent composition of species and abundance by major phyla for SBOO stations sampled during 2009. Data are expressed as annual means (range) for all stations combined; $n = 27$.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	50 (45–57)	73 (54–86)
Arthropoda (Crustacea)	21 (13–27)	12 (5–24)
Mollusca	15 (9–23)	8 (3–18)
Echinodermata	6 (3–9)	4 (2–9)
Other Phyla	8 (3–16)	3 (1–9)

Classification of Macrobenthic Assemblages

Results of the ordination and cluster analyses discriminated seven habitat-related macrobenthic assemblages (Figure 5.4, 5.5). These assemblages (cluster groups A–G) varied in terms of their species composition (i.e., specific taxa present) and the

Table 5.3
The 10 most abundant macroinvertebrates collected at the SBOO benthic stations sampled during 2009. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Species	Higher Taxa	Percent Occurrence	Abundance per Sample	Abundance per Occurrence
Most Abundant				
Spiophanes norrisi	Polychaeta: Spionidae	100	88.1	88.1
Monticellina siblina	Polychaeta: Cirratulidae	67	15.0	22.5
Euclymeninae sp A	Polychaeta: Maldanidae	87	9.7	11.1
Spiophanes duplex	Polychaeta: Spionidae	76	9.1	12.0
Notomastus latericeus	Polychaeta: Capitellidae	74	8.0	10.8
Mooreonuphis nebulosa	Polychaeta: Onuphidae	41	6.9	16.9
Mediomastus sp	Polychaeta: Capitellidae	85	5.2	6.1
Spiophanes berkeleyorum	Polychaeta: Spionidae	70	3.9	5.6
Ampelisca cristata cristata	Crustacea: Amphipoda	80	3.8	4.8
Ophiuroconis bispinosa	Echinodermata: Ophiurodia	63	3.8	6.0

relative abundance of those species, and occurred at sites separated by different depths and/or sediment microhabitats (Figure 5.6). The SIMPROF procedure indicated statistically significant non-random structure among samples ($\pi = 6.92$, $p < 0.001$), and an MDS ordination of the station/survey entities supported the validity of the cluster groups (Figure 5.4B). SIMPER analysis was used to identify species that were characteristic, though not always the most abundant, of some assemblages; i.e., the three most characteristic species for each cluster group are indicated in Figure 5.4A. A complete list of species comprising each group and their relative abundances can be found in Appendix D.1.

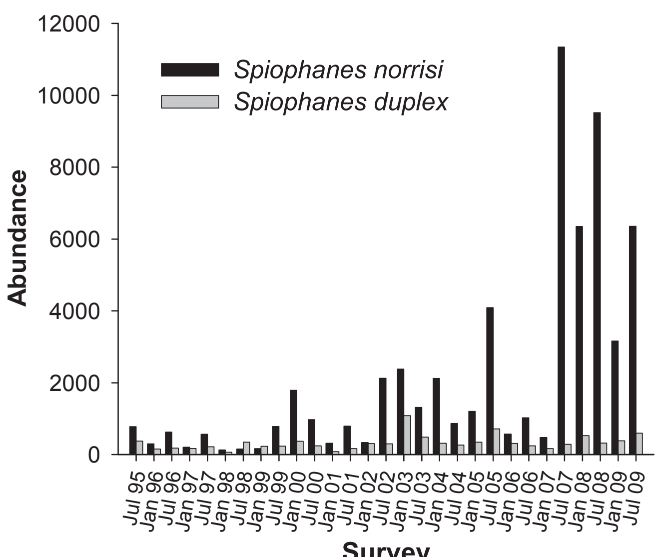
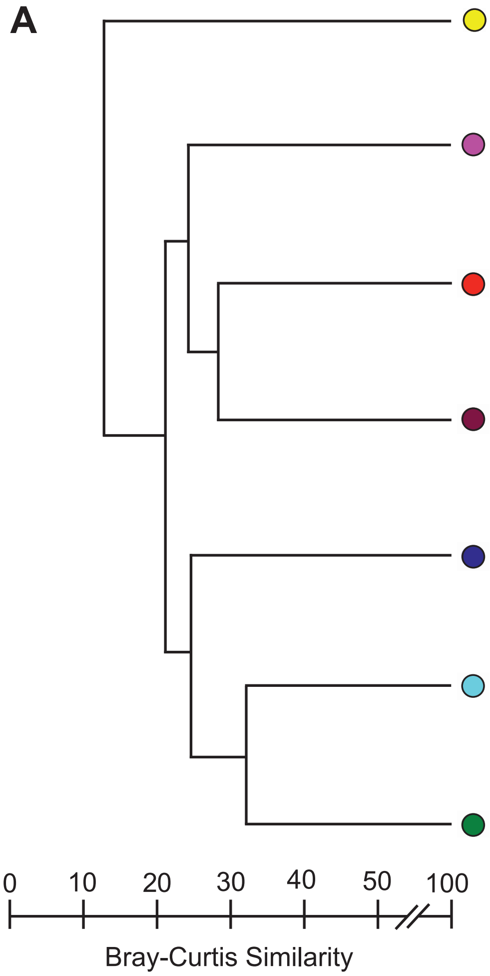


Figure 5.3
Total abundance of the polychaetes *Spiophanes norrisi* and *Spiophanes duplex* for each survey at the SBOO benthic stations from 1995–2009.

Cluster group A represented a shallow-shelf assemblage that occurred in January at station I18, which is located along the 19-m depth contour. This assemblage contained only 16 taxa and 21 individuals per 0.1 m^2, the lowest among all cluster groups. Juvenile ophiuroids *Amphiodia* sp, were present in this group, as were the polychaete Euclymeninae sp A and the ostracod *Euphilomedes carcharodonta*. The sediments characteristic of this sample contained the highest amounts of percent fines (44%) compared to the other group averages (i.e., 2–21%), and had a total organic carbon (TOC) concentration of 0.3% weight (% wt).

Cluster group B represented a shallow-shelf assemblage restricted to the January surveys at stations I34 and I23. This group was associated with very coarse sediments comprised almost entirely of sand and shell hash (i.e., only 7% fines). Although TOC concentrations tend to correlate with percent fines (see Chapter 4), TOC values for these two samples were relatively high at 2.8% wt on average. Species richness averaged 57 taxa and abundance averaged 341 individuals per 0.1 m^2. As in previous years (see City of San Diego 2007, 2009), this unique assemblage

A



CG	*n*	% Fines	TOC	SR	Abun	Characteristic Taxa
A	1	44	0.3	16	21	*Amphiodia* sp Euclymeninae sp A *Euphilomedes carcharodonta*
B	2	7	2.8	57	341	*Polycirrus* sp *Protodorvillea gracilis* *Hesionura coineaui difficilis*
C	12	2	0.1	59	404	*Spiophanes norrisi* *Scoloplos armiger* complex *Notomastus latericeus*
D	8	2	0.1	60	244	*Polycirrus* sp A *Ophiuroconis bispinosa* *Ampelisca cristata cristata*
E	4	21	0.5	101	317	*Axinopsida serricata* *Leptochelia dubia* *Euphilomedes carcharodonta*
F	7	8	0.2	61	232	*Glycinde armigera* *Ampelisca cristata cristata* *Spiophanes duplex*
G	20	21	0.4	96	437	*Ampelisca brevisimulata* *Euphilomedes carcharodonta* *Monticellina siblina*

B

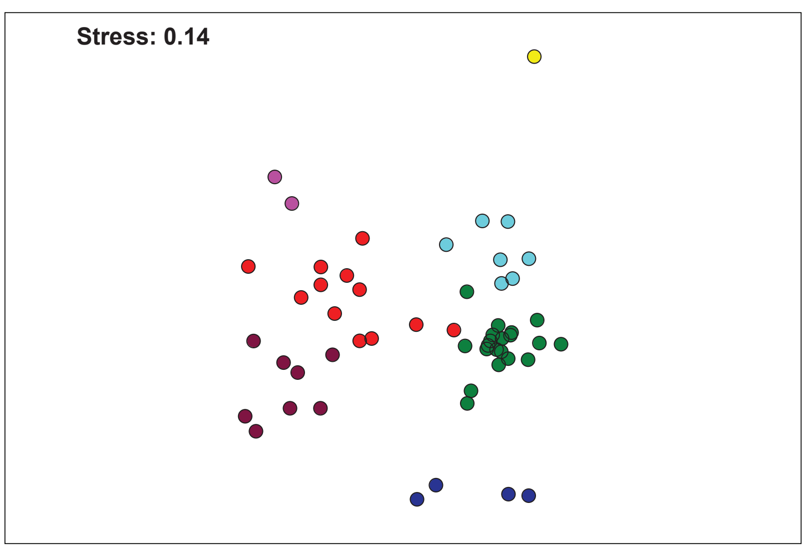


Figure 5.4

(A) Cluster results of the macrofaunal abundance data for the SBOO benthic stations sampled during winter and summer 2009. Data for percent fines, total organic carbon (TOC; % weight), species richness (SR), and infaunal abundance (Abun), are expressed as mean values per 0.1-m^2 grab over all stations in each group (CG). (B) MDS ordination based on square-root transformed macrofaunal abundance data for each station/survey entity. Cluster groups superimposed on station/surveys illustrate a clear distinction between faunal assemblages.

contained several polychaete species commonly found in sediments with coarse particles (e.g., *Hesionura coineaui difficilis*, *Hemipodia borealis*, and *Pisione* sp). The cephalochordate, *Branchiostoma californiense*, also associated with coarse sediment habitats, was present as well (Appendix D.1).

Cluster group C represented an assemblage that occurred at eight stations located mostly near the discharge site or south of the outfall at depths between 18–36 m. This assemblage averaged 59 taxa and 404 organisms per 0.1 m^2. Polychaetes were numerically dominant, with the spionid *Spiophanes norrisi,* the orbiniid *Scoloplos armiger* complex, and the capitellid *Notomastus latericeus* representing the three most characteristic taxa. The habitat at these sites was characterized by mixed but coarse sediments, especially red relict sand, with TOC values that averaged 0.1% wt.

Cluster group D represented an assemblage characteristic of four sites east of the SBOO located along the 38 and 55-m depth contours. This assemblage averaged 244 individuals and 60 taxa per 0.1 m^2. The three most characteristic species of this group were the terebellid polychaete *Polycirrus* sp A, the ophiuroid *Ophiuroconis bispinosa* and the amphipod *Ampelisca cristata cristata.* Sediments at these sites were comprised of red relict sands and averaged only 2% fines with TOC values of 0.1% wt on average.

Cluster group E represented a mid-shelf assemblage from stations located near the 55-m depth contour. This assemblage averaged 317 individuals and 101 taxa per 0.1 m^2, the latter representing the highest species richness for the region. The three most characteristic species included the thyasirid bivalve *Axinopsida serricata,* the tanaid *Leptochelia dubia* and the ostracod *E. carcharodonta*. The sediments associated with this group were mixed, composed of 21% fines and some coarse black sand with TOC values of 0.5% wt on average.

Cluster group F represented the shallowest overall assemblage sampled at five sites along the 19-m contour. Abundance averaged 232 individuals and species richness averaged 61 taxa per 0.1 m^2. The three most characteristic species in this assemblage were the goniadid polychaete *Glycinde armigera*, the amphipod *A. cristata cristata*, and the spionid polychaete *Spiophanes duplex*. Sediments at this site were relatively coarse (8% fines) and contained shell hash and organic debris with an average TOC value of 0.2% wt.

Cluster group G represented the most widespread macrobenthic assemblage present in 2009, comprising animals from 37% of the samples and 11 stations located mainly along the 19 and 28-m depth contours. This shallow shelf assemblage averaged 96 taxa and 437 individuals per 0.1 m^2. The top three characteristic species included the amphipod *Ampelisca brevisimulata*, the ostracod *E. carcharodonta*, and the cirratulid *Monticellina siblina*. The sediments associated with this assemblage

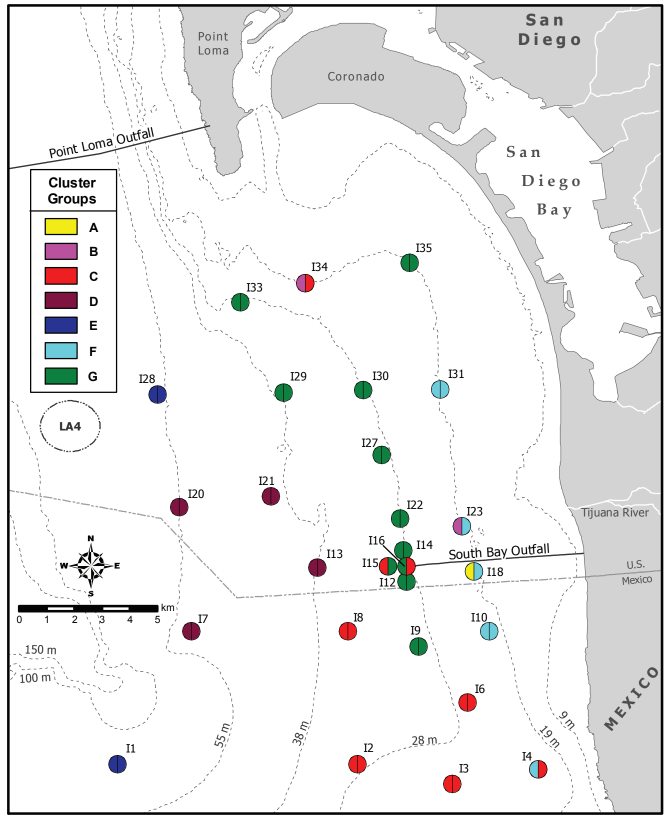


Figure 5.5
Spatial distribution of SBOO macrobenthic assemblages delineated by ordination and classification analyses (see Figure 5.4). Left half of circle represents cluster group affiliation for the January survey; right half represents the July survey.

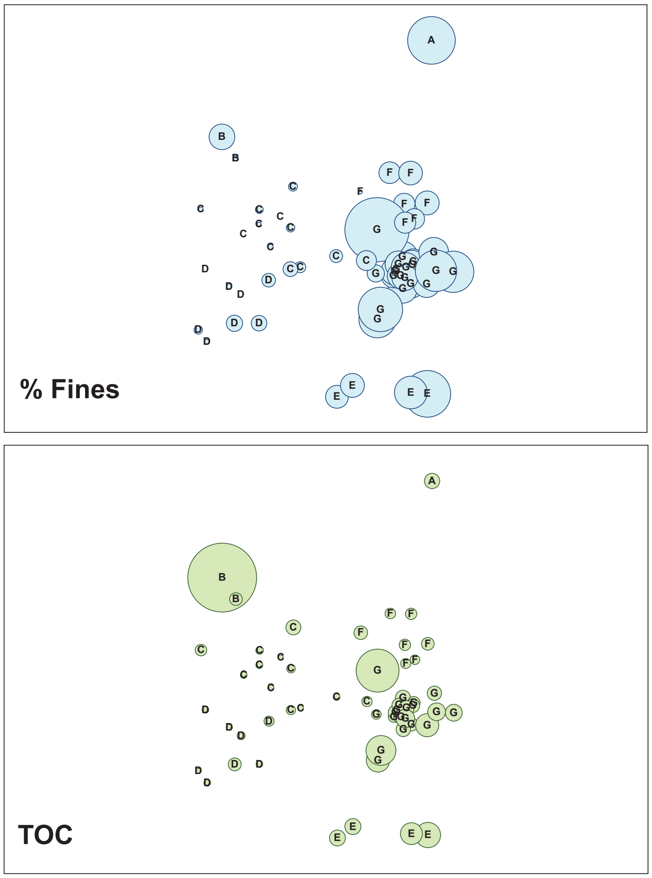


Figure 5.6
MDS ordination of SBOO benthic stations sampled during winter and summer 2009. Cluster groups A–G are superimposed on station/surveys. Percentages of fine particles and total organic carbon (TOC) in the sediments are further superimposed as circles that vary in size according to the magnitude of each value. Plots indicate associations of benthic assemblages with habitats that differ in sediment grain size and TOC. Stress = 0.14.

were characterized by some shell hash and 21% fines with TOC values of 0.4% wt on average.

Summary and Conclusions

Benthic macrofaunal assemblages surrounding the SBOO were similar in 2009 to those that occurred during previous years, including the period before initiation of wastewater discharge (e.g., see City of San Diego 2000, 2009). In addition, these assemblages were typical of those occurring in other sandy, shallow-, and mid-depth habitats throughout the Southern California Bight (SCB) (e.g., Thompson et al. 1987, 1993b; City of San Diego 1999, Bergen et al. 2001, Ranasinghe et al. 2003, 2007). For example, assemblages found at the majority of stations (i.e., cluster groups C and G) contained high numbers of the spionid polychaete *Spiophanes norrisi*, a species characteristic of shallow-water environments with coarser sediments in the SCB (see Bergen et al. 2001). These two groups represented sub-assemblages of the SCB benthos that differed in the relative abundances of dominant and co-dominant species. Such differences probably reflect variation in sediment structure. Consistent with historical values, sediments in the shallow SBOO region generally were coarser south of the outfall relative to the more northern stations (see Chapter 4).

In contrast, the group E assemblage occurs in mid-depth shelf habitats that probably represent a transition between the shallow sandy sediments common in the area and the finer mid-depth sediments characteristic of much of the SCB mainland shelf (see Barnard and Ziesenhenne 1961, Jones 1969, Fauchald and Jones 1979, Thompson et al. 1993a, EcoAnalysis et al. 1993, Diener and Fuller 1995). The group B assemblage, restricted to stations I34 and I23, was different from assemblages found at any other station. Several species of polychaete worms (i.e., *Pareurythoe californica*, *Typosyllis* sp SD1, *Hemipodia borealis, Hesionura coineaui difficilis*, *Micropodarke dubia*, and *Pisione* sp) not common elsewhere in the region were characteristic of this assemblage. This pattern is similar to that observed previously at these stations from 2003 through 2008 (see City of San Diego 2004–2009). Analysis of sediment quality data provides some evidence relevant to explaining the occurrence of the B assemblage, which represented only the January samples from the above two stations and where associated sediments were relatively coarse (see Chapter 4).

Results from multivariate analyses revealed no clear spatial patterns relative to the ocean outfall. Comparisons of the biotic data to the physico-chemical data suggest that macrofaunal distribution and abundance in the region varied primarily along depth and sediment gradients and to a lesser degree, TOC levels (see Hyland et al. 2005). Populations of the spionid polychaete *Spiophanes norrisi* collected during 2009 were the third highest recorded since monitoring began in 1995. Consequently, the high numbers for this species influenced overall abundance values in the region. Patterns of region-wide abundance fluctuations over time appear to mirror historical patterns of *S. norrisi* while temporal fluctuations in the populations of this and similar species occur elsewhere in the region and may correspond to large-scale oceanographic conditions (see Zmarzly et al. 1994). Overall, analyses of temporal patterns suggest that the benthic community in the South Bay region has not been significantly impacted by wastewater discharge. For example, while species richness and total macrofaunal abundance were at or near their historical highs during 2009, annual means from the four nearfield stations were similar to those located further away (see City of San Diego 2006–2009). Diversity (H') and evenness (J') values have also remained relatively stable since monitoring began in 1995. In addition, environmental disturbance index averages such as the BRI continue to be generally characteristic of assemblages from undisturbed habitats.

Annual means of macrofaunal parameters help to give an integrated view of community health, but can sometimes mask anomalous samples at an individual station. For example, one sample from station I16 in January was relatively depauperate of taxa (i.e., 7 taxa and 39 individuals) with a resulting BRI value of 36, though macrofaunal parameters from a replicate sample taken on the same day fell within normal ranges (i.e., 6 taxa, 242 individuals, and BRI = 23). The differences between these two samples could be accounted for by sediment habitat heterogeneity at relatively small spatial scales (i.e., meters). Sediment habitats can change over time as well. For example, sediments at I16 in January differed markedly from July and from historical values, with the depauperate sample sieved from sediments containing mostly silt (see Chapter 4). Station I18 in January also contained historically high fines, low species richness and low infaunal abundance compared to typical values.

Anthropogenic impacts are known to have spatial and temporal dimensions that can vary depending on a range of biological and physical factors. Such impacts can be difficult to detect, and specific effects of the SBOO discharge on the local macrobenthic community could not be identified during 2009. Furthermore, benthic invertebrate populations exhibit substantial spatial and temporal variability that may mask the effects of any disturbance event (Morrisey et al. 1992a, b; Otway 1995). Although some changes have occurred near the SBOO over time, benthic assemblages in the area remain similar to those observed prior to discharge and to natural indigenous communities characteristic of similar habitats on the southern California continental shelf.

Literature Cited

Barnard, J.L. and F.C. Ziesenhenne. (1961). Ophiuroidea communities of southern Californian coastal bottoms. Pacific Naturalist, 2: 131–152.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

Bilyard, G.R. (1987). The value of benthic infauna in marine pollution monitoring studies. Marine Pollution Bulletin, 18(11): 581–585.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000). Final Baseline Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2005). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2004. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R. and M. Ainsworth. (1993). A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series 92: 205–209.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Diener, D.R. and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. Bulletin of the Southern California Academy of Sciences, 94: 5–20.

EcoAnalysis, Southern California Coastal Water Research Project, and Tetra Tech. (1993). Analyses of ambient monitoring data for the Southern California Bight. Final Report to U.S. EPA, Wetlands, Oceans, and Estuaries Branch, Region IX, San Francisco, CA.

Fauchald, K. and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. Report 19, Series 2. In: Southern California Outer Continental Shelf Environmental Baseline Study, 1976/1977 (Second Year) Benthic Program. Principal Investigators Reports, Vol. II. Science Applications, Inc. La Jolla, CA.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and W.A. Deben. (1994). Optimum macrobenthic sampling protocol for detecting pollution impacts in the Southern California Bight. Environmental Monitoring and Assessment, 29: 127–153.

Field, J.G., K.R. Clarke, and R.M. Warwick. (1982). A practical strategy for analyzing multiple species distribution patterns. Marine Ecology Progress Series, 8: 37–52.

Gray, J.S. (1979). Pollution-induced changes in populations. Philosophical Transactions of the Royal Society of London (Series B), 286: 545–561.

Hartley, J.P. (1982). Methods for monitoring offshore macrobenthos. Marine Pollution Bulletin, 12: 150–154.

Hyland J., L. Balthis, I. Karakassis, P. Magni, A. Petrov, J. Shine, O. Vestergaard, and R. Warwick. (2005). Organic carbon content of sediments as an indicator of stress in the marine benthos. Marine Ecology Progress Series, 295: 91–103.

Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monograph of Marine Biology, 4: 1–219.

Morrisey, D.J., L. Howitt, A.J. Underwood, and J.S. Stark. (1992a). Spatial variation in soft-sediment benthos. Marine Ecology Progress Series, 81: 197–204.

Morrisey, D.J., A.J. Underwood, L. Howitt, and J.S. Stark. (1992b). Temporal variation in soft-sediment benthos. Journal of Experimental Marine Biology and Ecology, 164: 233–245.

Otway, N.M. (1995). Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. Marine Pollution Bulletin, 31: 347–354.

Pearson, T.H. and R. Rosenberg. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanography and Marine Biology Annual Review, 16: 229–311.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications, 11(4): 1073–1087.

Snelgrove P.V.R., T.H. Blackburn, P.A. Hutchings, D.M. Alongi, J.F. Grassle, H. Hummel, G. King, I. Koike, P.J.D. Lambshead, N.B. Ramsing, V. Solis-Weiss. (1997). The importance of marine sediment biodiversity in ecosystem processes. Ambio, 26: 578–583.

Swartz, R.C., F.A. Cole, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B., J. Dixon, S. Schroeter, and D.J. Reish. (1993a). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA.

Thompson, B.E., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 reference site survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B.E., D. Tsukada, and D. O’Donohue. (1993b). 1990 reference site survey. Technical

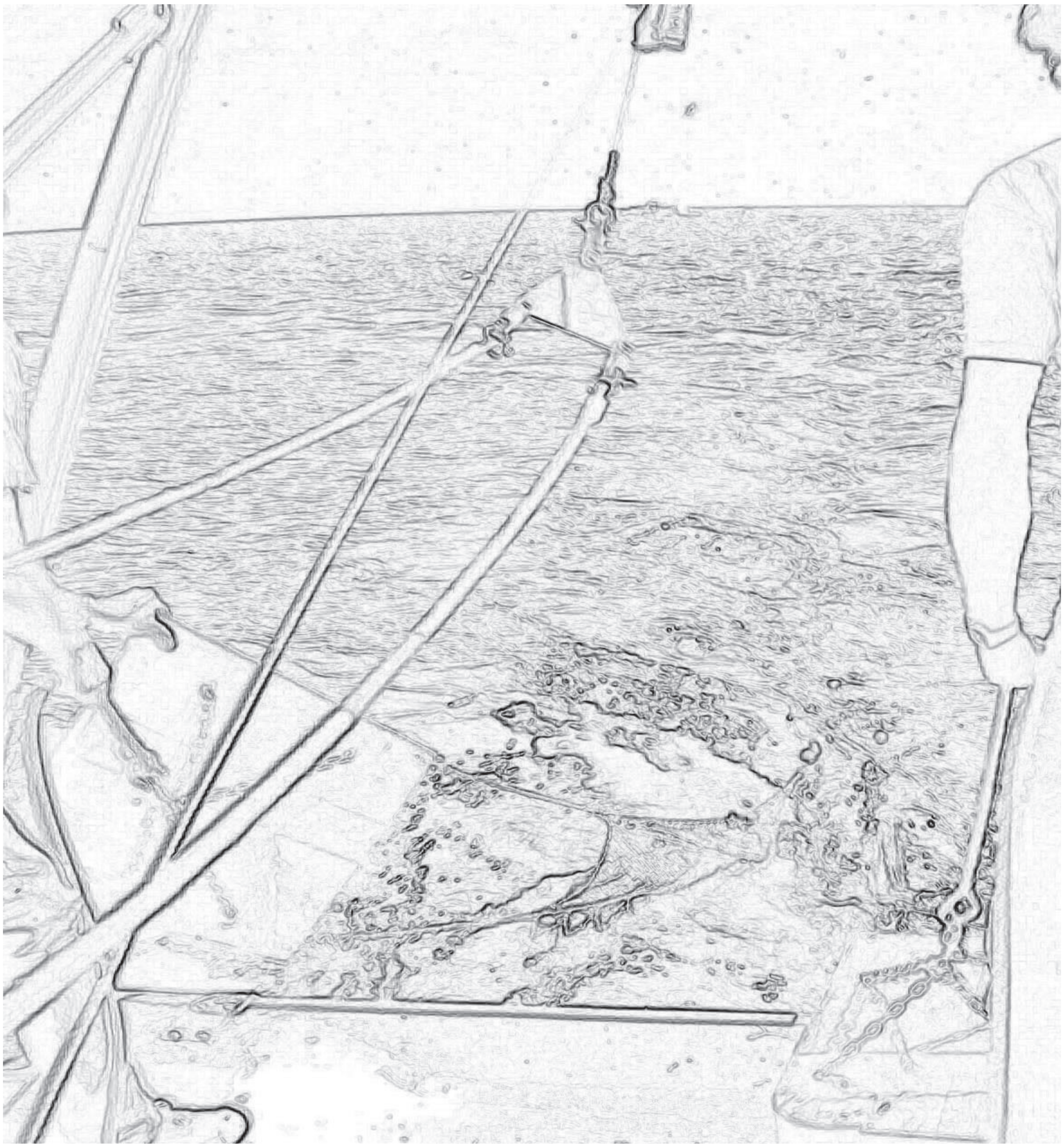
Report No. 269, Southern California Coastal Water Research Project, Long Beach CA.

[U.S. EPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: Relation to anthropogenic and natural events. Marine Biology, 118: 293–307.

Chapter 6
Demersal Fishes
and Megabenthic Invertebrates



Chapter 6. Demersal Fishes and Megabenthic Invertebrates

INTRODUCTION

Marine fishes and invertebrates are conspicuous members of continental shelf habitats, and assessment of their communities has become an important focus of ocean monitoring programs throughout the world. Assemblages of bottom dwelling (demersal) fishes and relatively large (megabenthic), mobile invertebrates that live on the surface of the seafloor have been sampled extensively for more than 30 years on the mainland shelf of the Southern California Bight (SCB), primarily by programs associated with municipal wastewater and power plant discharges (Cross and Allen 1993). More than 100 species of demersal fishes inhabit the SCB, while the megabenthic invertebrate fauna consists of more than 200 species (Allen 1982, Allen et al. 1998, 2002, 2007). For the region surrounding the South Bay Ocean Outfall (SBOO), the most common trawl-caught fishes include speckled sanddab, longfin sanddab, hornyhead turbot, California halibut, and California lizardfish. Common trawl-caught invertebrates include various echinoderms (e.g., sea stars, sea urchins, sea cucumbers, sand dollars), crustaceans (e.g., crabs, shrimp), molluscs (e.g., marine snails, octopuses), and other taxa.

Demersal fish and megabenthic invertebrate communities are inherently variable and may be influenced by both anthropogenic and natural factors. These organisms live in close proximity to the seafloor and are therefore exposed to contaminants of anthropogenic origin that may accumulate in the sediments via deposition from both point and non-point sources (e.g., discharges from ocean outfalls and storm drains, surface runoff from watersheds, outflows from rivers and bays, disposal of dredge materials). Natural factors that may affect these organisms include prey availability (Cross et al. 1985), bottom relief and sediment structure (Helvey and Smith 1985), and changes in water temperatures associated with large scale oceanographic events such as El Niño/La Niña oscillations (Karinen et al. 1985). These factors can affect migration patterns of adult fish or the recruitment of juveniles into an area (Murawski 1993). Population fluctuations that affect species diversity and abundance of both fishes and invertebrates may also be due to the mobile nature of many species (e.g., fish schools, urchin aggregations).

The City of San Diego has been conducting trawl surveys in the area surrounding the SBOO since 1995. These surveys are designed to monitor the effects of wastewater discharge on the local marine biota by assessing the structure and stability of the trawl-caught fish and invertebrate communities. This chapter presents analyses and interpretations of the data collected during the 2009 trawl surveys. A long-term analysis of changes in these communities from 1995 through 2009 is also presented.

Materials and Methods

Field Sampling

Trawl surveys were conducted at seven fixed monitoring stations around the SBOO during 2009 (Figure 6.1). These surveys were conducted during January (winter), April (spring), July (summer), and October (fall) for a total of 28 community trawls during the year. These stations, designated SD15–SD21, are located along the 28-m depth contour, and encompass an area ranging from south of Point Loma, California (USA) to an area off Punta Bandera, Baja California (Mexico). A single trawl was performed at each station during each survey using a 7.6-m Marinovich otter trawl fitted with a 1.3-cm cod-end mesh net. The net was towed for 10 minutes bottom time at a speed of about 2.0 knots along a predetermined heading.

The total catch from each trawl was brought onboard ship for sorting and inspection. All fishes and invertebrates captured were identified to species or to the lowest taxon possible. If an animal could

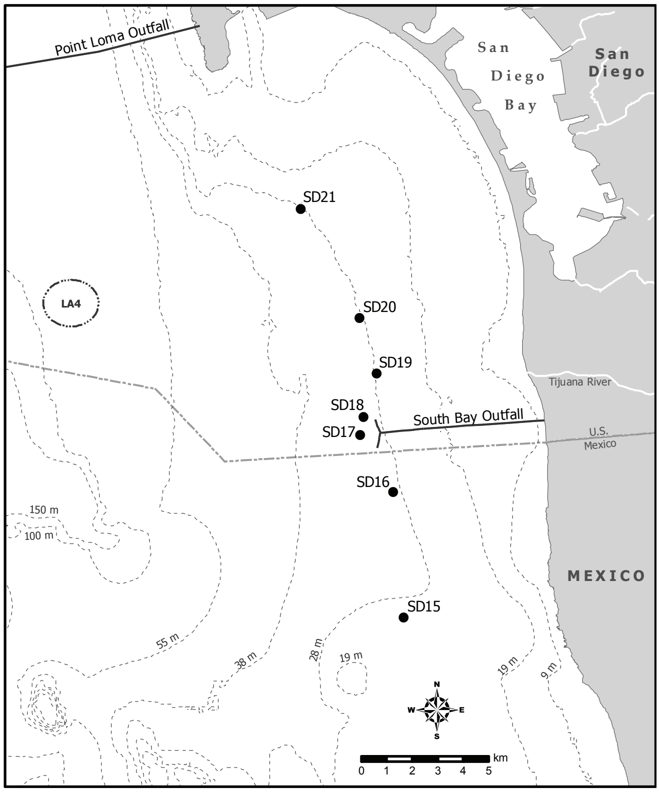


Figure 6.1
Otter trawl station locations, South Bay Ocean Outfall Monitoring Program.

not be identified in the field, it was returned to the laboratory for further identification. For fishes, the total number of individuals and total biomass (kg, wet weight) were recorded for each species. Additionally, each individual fish was inspected for physical anomalies or indicators of disease (e.g., tumors, fin erosion, discoloration) as well as the presence of external parasites, and then measured to the nearest centimeter size class (standard lengths). For invertebrates, the total number of individuals was recorded per species. Due to the small size of most organisms, invertebrate biomass was typically measured as a composite weight of all species combined; however, large or exceptionally abundant species were weighed separately.

Data Analyses

Populations of each fish and invertebrate species were summarized as percent abundance, frequency of occurrence, mean abundance per haul, and mean abundance per occurrence. In addition, species richness (number of taxa), total abundance, total biomass, and Shannon diversity index (H') were calculated for each station. For historical comparisons, the data were grouped as "nearfield" stations (SD17, SD18), "south farfield" stations (SD15, SD16), and "north farfield" stations (SD19, SD20, SD21). The two nearfield stations were those located closest to the outfall (i.e., within 1000 m of the north or south diffuser legs).

A long-term multivariate analysis of demersal fish communities in the region was performed using data collected from 1995 through 2009. However, in order to eliminate noise due to natural seasonal variation in populations, this analysis was limited to data for the July surveys only over these 15 years. PRIMER software was used to examine spatio-temporal patterns in the overall similarity of fish assemblages in the region (see Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking, and ordination by non-metric multidimensional scaling (MDS). The fish abundance data were square root transformed and the Bray-Curtis measure of similarity was used as the basis for classification. Because species composition was sparse at some stations, a "dummy" species with a value of one was added to all samples prior to computing similarities (see Clarke and Gorley 2006). SIMPER analysis was subsequently used to identify which species primarily account for observed differences between cluster groups, as well as to identify species typical of each group.

Results and Discussion

Fish Community

Thirty-four species of fish were collected in the area surrounding the SBOO in 2009 (Table 6.1, Appendix E.1). The total catch for the year was 6192 individuals, representing an average of about 221 fish per trawl. As in previous years, speckled sanddabs were dominant, occurring in every haul and accounting for 38% of the total number of fishes collected. However, California lizardfish and

Table 6.1

Demersal fish species collected in 28 trawls in the SBOO region during 2009. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Speckled sanddab	38	100	84	84	Pacific pompano	<1	4	<1	4
California lizardfish	29	100	64	64	Pink seaperch	<1	11	<1	1
Yellowchin sculpin	15	61	33	55	Bigmouth sole	<1	11	<1	1
Roughback sculpin	9	96	19	20	Juvenile rockfish	<1	7	<1	2
Longfin sanddab	2	64	5	8	Sarcastic fringehead	<1	4	<1	3
Longspine combfish	2	46	4	8	Barcheek pipefish	<1	4	<1	2
Hornyhead turbot	1	93	3	3	Bay pipefish	<1	4	<1	2
California tonguefish	1	64	2	4	Spotted cuskeel	<1	7	<1	1
Plainfin midshipman	1	54	1	2	White croaker	<1	4	<1	2
California scorpionfish	<1	39	1	2	Giant kelpfish	<1	4	<1	1
Shiner perch	<1	7	1	10	Kelp bass	<1	4	<1	1
English sole	<1	39	1	1	Kelp pipefish	<1	4	<1	1
Fantail sole	<1	32	<1	1	Northern anchovy	<1	4	<1	1
Pygmy poacher	<1	18	<1	1	Pacific sanddab	<1	4	<1	1
California skate	<1	21	<1	1	Juvenile sea bass	<1	4	<1	1
Specklefin midshipman	<1	14	<1	1	Señorita	<1	4	<1	1
California halibut	<1	14	<1	1	Spotted turbot	<1	4	<1	1

yellowchin sculpin were also abundant, accounting for 29% and 15% of the total number of fishes collected, respectively. Together these three species accounted for 82% of all fishes collected in 2009. Like the speckled sanddab, California lizardfish occurred in every haul, whereas yellowchin sculpin occurred in 61%. Other species collected frequently (>50% of the trawls) included roughback sculpin, longfin sanddab, hornyhead turbot, California tonguefish, and plainfin midshipman. The majority of species captured in the South Bay outfall region tended to be relatively small fish with an average length <20 cm (see Appendix E.1). Although larger species such as the California skate and California halibut were also caught during the year, they were relatively rare.

During 2009, species richness (number of taxa) and diversity (H') values for the South Bay fish assemblages were relatively low compared to values reported previously for other areas of the SCB (e.g., Allen et al. 1998, 2002, 2007), while abundance and biomass values varied widely (Table 6.2). No more than 14 species occurred in any one haul, and the corresponding H' values were all less than 2.2. As in previous years, trawls from station SD15 located the farthest south in Mexican waters had the lowest average species richness (6 species) and diversity (H' = 0.84) values. Total abundance ranged from 69 to 518 fishes per haul over all stations, which generally co-varied with populations of speckled sanddabs, California lizardfish, yellowchin sculpin, and roughback sculpin (see Appendix E.2). Biomass varied from 1.3 to 7.6 kg per haul, with higher biomass values coincident with greater numbers of fishes as expected (Appendix E.3).

Although average species richness values for SBOO demersal fish assemblages have remained within a narrow range over the years (i.e., 5–14 species/station/year), the average abundance per haul has fluctuated greatly (i.e., 28–308 fish/station/year) mostly in response to population fluctuations of a few dominant species (see Figure 6.2, 6.3). For example, average abundance at four of the seven stations decreased between 2008 and 2009 (SD16, SD19, SD20, SD21); these reductions match drops in average speckled sanddab numbers at the same stations. In contrast, overall abundances increased at stations SD15, SD17, and SD18, reflecting greater numbers of yellowchin sculpin and California lizardfish. Whereas population fluctuations of common

Table 6.2

Summary of demersal fish community parameters for SBOO stations sampled during 2009. Data are included for species richness (number of species), abundance (number of individuals), diversity (H'), and biomass (kg, wet weight); SD = standard deviation.

Station	Jan	Apr	Jul	Oct	Annual Mean	Annual SD	Station	Jan	Apr	Jul	Oct	Annual Mean	Annual SD
Species Richness							*Abundance*						
SD15	7	5	6	6	6	1	SD15	75	153	182	146	139	45
SD16	6	8	9	7	8	1	SD16	164	123	356	110	188	114
SD17	9	13	11	9	11	2	SD17	93	154	465	518	308	215
SD18	11	12	9	9	10	2	SD18	220	219	136	356	233	91
SD19	8	11	11	8	10	2	SD19	135	115	256	414	230	138
SD20	8	9	12	11	10	2	SD20	129	171	382	250	233	111
SD21	13	14	12	11	13	1	SD21	156	172	473	69	218	176
Survey Mean	9	10	10	9			Survey Mean	139	158	321	266		
Survey SD	2	3	2	2			Survey SD	48	35	133	169		
Diversity							*Biomass*						
SD15	0.97	0.62	0.89	0.86	0.84	0.15	SD15	2.3	2.6	2.3	1.8	2.2	0.3
SD16	0.85	1.03	1.44	1.20	1.13	0.25	SD16	1.8	4.7	4.5	2.9	3.5	1.4
SD17	1.18	1.61	1.34	0.98	1.28	0.27	SD17	1.5	7.6	4.2	4.6	4.5	2.5
SD18	1.50	1.77	1.30	1.30	1.47	0.22	SD18	4.4	5.2	2.3	3.7	3.9	1.2
SD19	0.88	1.57	1.67	0.89	1.25	0.43	SD19	2.0	3.7	5.3	4.2	3.8	1.4
SD20	0.88	1.16	1.61	1.68	1.33	0.38	SD20	1.3	3.8	5.8	2.8	3.4	1.9
SD21	1.83	1.83	1.60	2.11	1.84	0.21	SD21	3.7	7.2	6.2	3.1	5.0	2.0
Survey Mean	1.16	1.37	1.41	1.29			Survey Mean	2.4	5.0	4.4	3.3		
Survey SD	0.38	0.44	0.27	0.46			Survey SD	1.2	1.9	1.6	0.9		

species such as speckled sanddab, California lizardfish, roughback sculpin, and yellowchin sculpin tend to occur across large portions of the study area (i.e., over multiple stations), intra-station variability is most often associated with large hauls of schooling species that occur less frequently. Examples of this include (1) large hauls of white croaker which occurred primarily at station SD21 in 1996; (2) a large haul of northern anchovy which occurred in a single haul from station SD16 in 2001; (3) a large haul of Pacific pompano which was captured in a single haul at station SD21 in 2008. Overall, none of the observed changes appear to be associated with wastewater discharge.

Classification analyses of long-term data (1995–2009, July surveys only) discriminated between eight main types of fish assemblages in the South Bay region (Figure 6.4). These assemblages (cluster groups A–H) can be distinguished by differences in the relative abundances of the common species present, although most were dominated by speckled sanddabs. The distribution of assemblages in 2009 was generally similar to that seen in previous years, especially between 2003–2008, and no patterns appear to be associated with proximity to the outfall. Instead, most differences appear more closely related to large-scale oceanographic events (e.g., El Niño in 1998) or the unique characteristics of a specific station location. For example, station SD15 located far south of the outfall off northern Baja California often grouped apart from the remaining stations. The composition and main characteristics of each cluster group are described below (Table 6.3, Appendix E.4).

Cluster groups A, B, and C had the fewest fish per haul (i.e., 38 fish/4 species for group A;

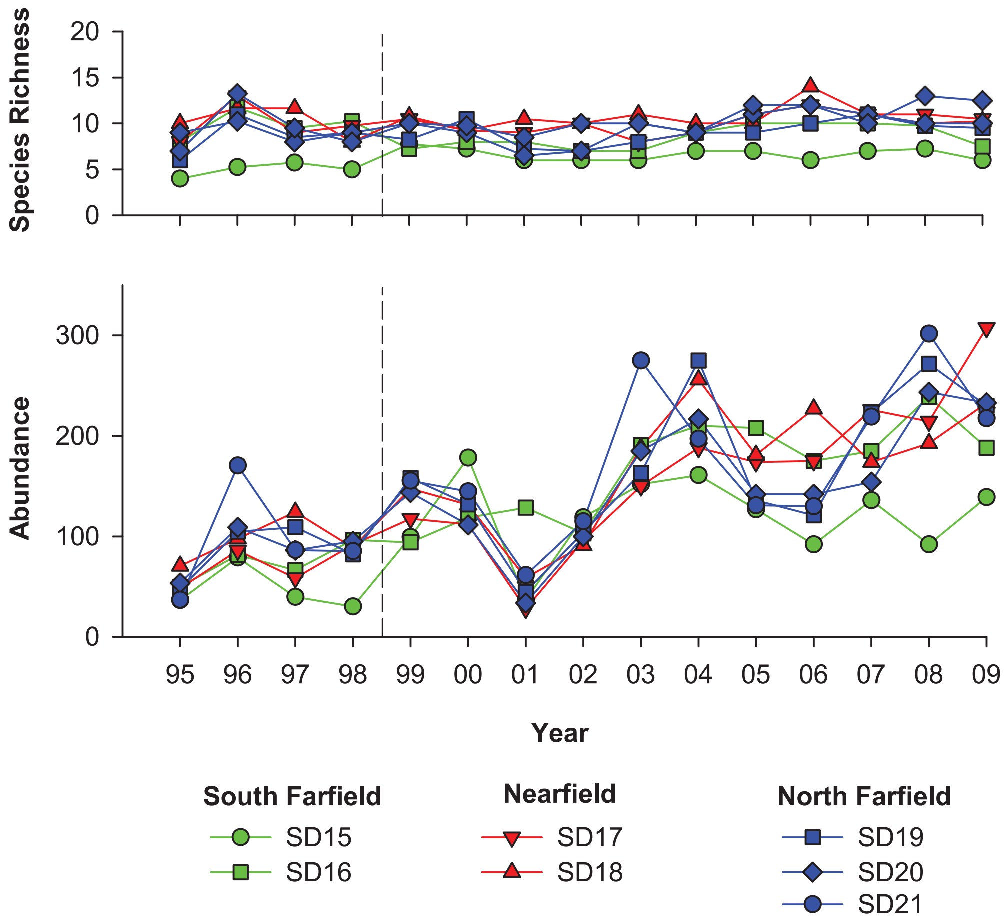


Figure 6.2

Species richness and abundance of demersal fish collected at each SBOO trawl station between 1995 and 2009. Data are annual means; $n=2$ in 1995 and $n=4$ between 1996–2009. Dashed line represents initiation of wastewater discharge.

17 fish/7 species for group B; 38 fish/7 species on average for group C), which reflected the relative lack of speckled sanddabs in these three groups compared to the other cluster groups (Table 6.3). These groups were further distinguished from the other cluster groups by their relative (but usually lower) abundance of several common species, including longfin sanddab, yellowchin sculpin, California lizardfish, hornyhead turbot, roughback sculpin and English sole (Appendix E.4). Assemblages represented by group C differed from those represented by groups A and B in the relative contribution of speckled sanddabs, California lizardfish, California scorpionfish, and hornyhead turbot. The assemblage represented by group A was from station SD15 in 1998 and the assemblage represented by group B was from station SD17 in 2001. The fish assemblages represented by group C were collected at four stations sampled in July 1997 (i.e., southern stations SD15 and SD16, station SD17 near the outfall, northern station SD20) and every station except SD17 and SD21 during July 2001 (Figure 6.4).

Cluster group D comprised assemblages from the two northernmost stations (SD20, SD21) sampled in 1995, as well as from every station except SD15 sampled during warm water conditions associated with the 1998 El Niño (Figure 6.4). This group averaged about 64 individuals and 9 species per haul, and was characterized by the second lowest abundance of speckled sanddabs (12 fish/haul) (Table 6.3). The dominant species in this group was California lizardfish (~24 fish/haul) followed by longfin sanddabs (~12 fish/haul) and speckled sanddabs (as above); the relative abundance of these species helped distinguish this group from all of the others (Appendix E.4).

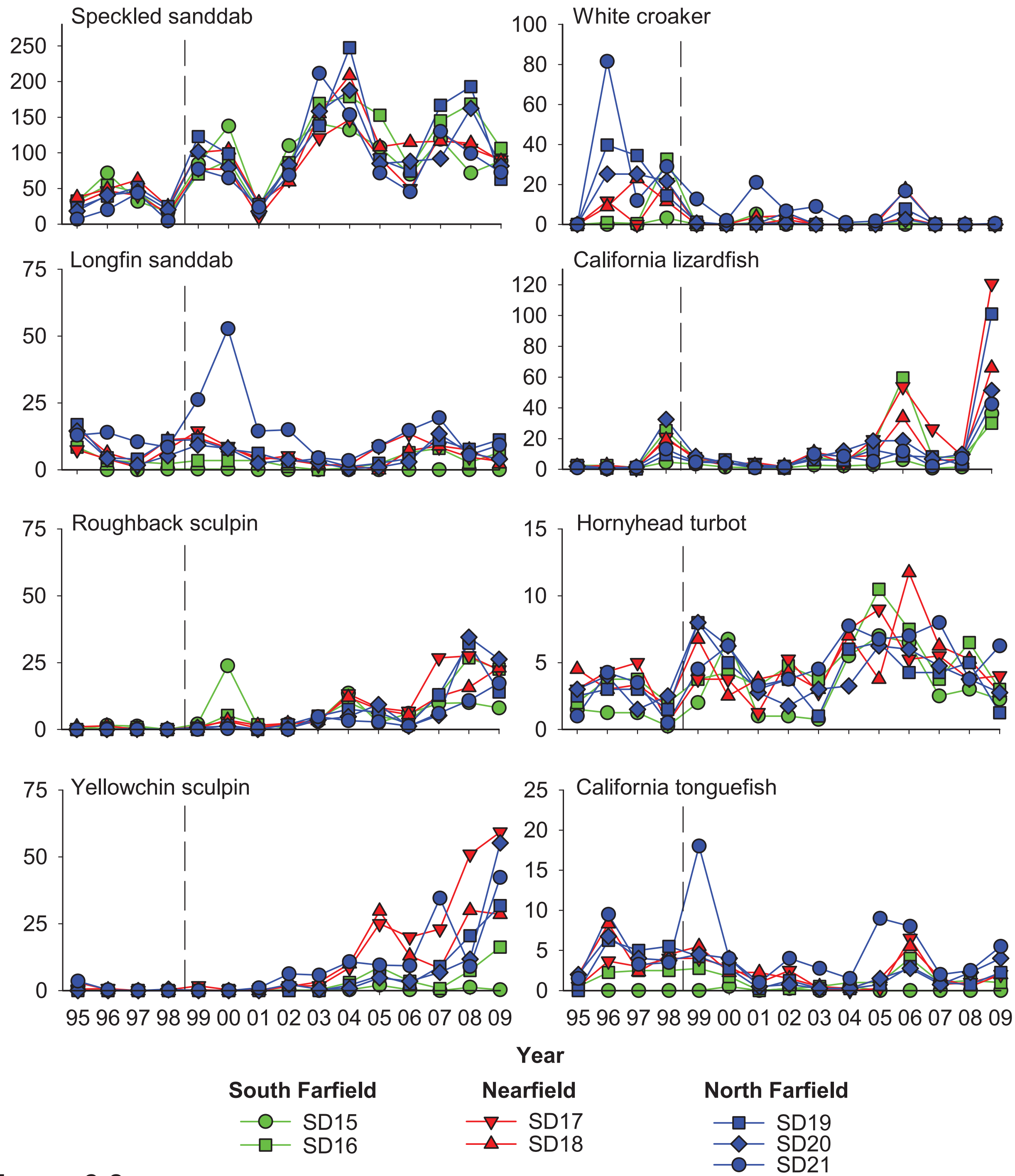


Figure 6.3
Abundance of the eight most abundant fish species collected in the SBOO region between 1995 and 2009. Data are annual means per station; $n=2$ in 1995 and $n=4$ between 1996–2009. Dashed line represents initiation of wastewater discharge.

Cluster group E was the third largest group and represented assemblages from 11 of the 14 station-surveys during 1995–1996 (i.e., representing all seven sites) and one or two stations each during 1997 (SD19, SD21), 1999 (SD17, SD21), 2000 (SD20, SD21), 2001 (SD21), and 2002 (SD18, SD21) (Figure 6.4). This group also represented assemblages from a few hauls at SD21 in 2005–2006. Similar to most other groups, the dominant species was the speckled sanddab (~62 fish/haul) (Table 6.3). Group E was also characterized by the greatest number of hornyhead turbots on average and had twice as many longfin sanddabs (~24 fish/haul) as in the other groups. The relative abundance of speckled

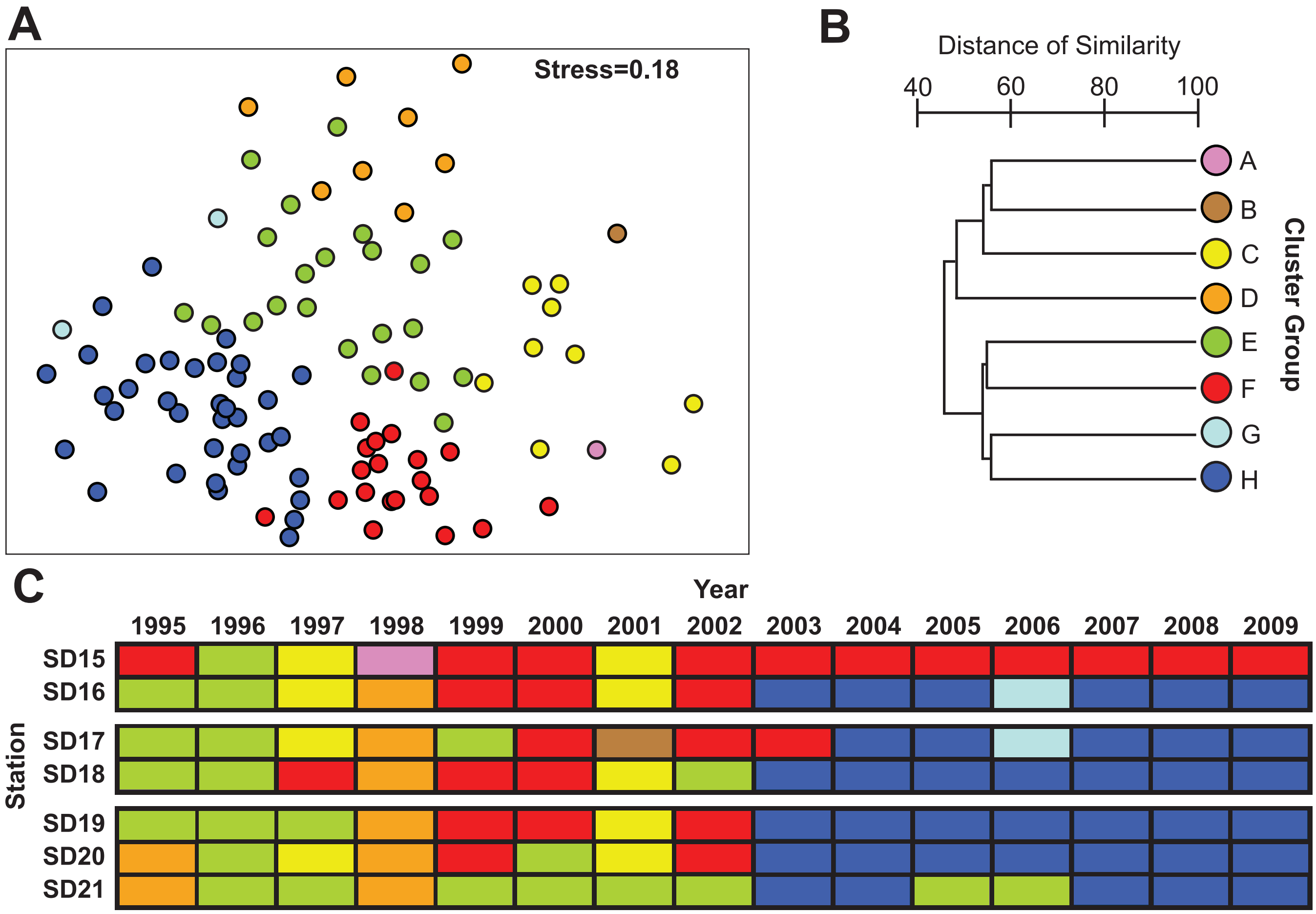


Figure 6.4
Results of multivariate analyses of demersal fish assemblages collected at SBOO stations SD15–SD21 between 1995 and 2009 (July surveys only). Data are presented as (A) MDS ordination, (B) a dendrogram of major cluster groups, and (C) a matrix showing distribution of cluster groups over time.

and longfin sanddabs, as well as California tonguefish, English sole, and hornyhead turbot distinguished this assemblage from the other cluster groups (Appendix E.4).

Cluster group F was the second largest group and comprised assemblages that occurred at a mix of sites sampled during all years except 1996, 1998, and 2001. This included station SD15 in 11 out of 15 surveys and a majority of the other stations sampled during 1999, 2000, and 2002 (Figure 6.4). Group F was characterized by the second highest average abundance of speckled sanddabs (~105 fish/haul) and very few other species (Table 6.3). The higher numbers of speckled sanddabs and lower numbers of various common species such as longfin sanddabs, California tonguefish, English sole, California lizardfish, yellowchin sculpin, and hornyhead turbot differentiated this group from the others (Appendix E.4).

Cluster group G represented the fish assemblages present only at stations SD16 and SD17 sampled in July 2006 (Figure 6.4). This group was unique in that it was characterized by more than 200 California lizardfish per haul, which was more than an order of magnitude greater for this species than in any other cluster group (Table 6.3). The second and third most abundant species comprising this group were the speckled sanddab (~56 fish/haul) and yellowchin sculpin (~15 fish/haul). The relative abundance of speckled sanddabs and hornyhead turbots distinguished this cluster group from the largest cluster group H (Appendix E.4).

Table 6.3

Description of cluster groups A–H defined in Figure 6.4. Data include number of hauls, mean species richness, mean total abundance, and mean abundance of the five most abundant species for each station group. Bold values indicate species that were considered “characteristic” of that group according to SIMPER analyses (i.e., similarity/ standard deviation ≥ 2.0).

	Group A	Group B	Group C	Group D	Group E	Group F	Group G	Group H
Number of Hauls	1	1	9	8	22	25	2	37
Mean Species Richness	4	7	7	9	10	6	8	10
Mean Abundance	38	17	38	64	117	120	299	235
Species				**Mean Abundance**				
California lizardfish	14	2	1	24	3	5	**212**	23
Speckled sanddab	22	**8**	**25**	**12**	**62**	**105**	**56**	**145**
Yellowchin sculpin	—	—	—	1	3	<1	15	33
Longfin sanddab	—	1	<1	**12**	24	<1	5	8
Hornyhead turbot	—	**1**	4	3	**6**	3	**4**	**4**
Roughback sculpin	—	—	—	—	1	<1	3	11
California tonguefish	—	—	1	2	5	1	3	2
English sole	—	—	<1	5	3	<1	2	3
California scorpionfish	—	3	2	<1	1	1	1	1
Spotted turbot	1	—	3	1	1	2	—	1
Fantail sole	1	1	<1	1	1	<1	—	<1
California skate	—	1	<1	<1	—	<1	—	<1

Cluster group H represented the assemblages from about 76% of the trawls performed from 2003 through 2009 (Figure 6.4). Assemblages represented by this group were characterized by having the highest number of speckled sanddabs (~145 fish/haul; Table 6.3), and were also distinguished from the other cluster groups by relatively high numbers of yellowchin and roughback sculpin (Appendix E.4). The larger hauls of speckled sanddabs that started to occur in 1999 (e.g., represented by cluster group F) versus previous years (e.g., represented by cluster groups C, D, and E), and that continued to increase over the time period represented by group H coincide with colder water conditions associated with oceanographic events such as La Niña (see Chapter 2).

Physical Abnormalities and Parasitism

Demersal fish populations appeared healthy in the SBOO region during 2009. There were no incidences of fin rot, discoloration, skin lesions, tumors, or any other physical abnormalities or indicators of disease among fishes collected during the year. Evidence of parasitism was also very low for trawl-caught fishes in the region. Only three external parasites were observed still attached to their host. These included a leech (Annelida, Hirudinea) attached to a hornyhead turbot at station SD18 in October, the cymothoid isopod *Elthusa vulgaris* attached to a speckled sanddab at station SD15 in April, and an unidentified parasite attached to a speckled sanddab at station SD15 in January. In addition to the isopod specimen identified on the speckled sanddab mentioned above, eight other *E. vulgaris* were identified as part of the trawl catch throughout the year (see Appendix E.5). Since cymothoids often become detached from their hosts during retrieval and sorting of the trawl catch, it is unknown which fishes were actually parasitized by these isopods. However, *E. vulgaris* is known to be especially common on sanddabs and California lizardfish in southern California waters, where it may reach infestation rates of 3% and 80%, respectively (see Brusca 1978, 1981).

Invertebrate Community

A total of 1055 megabenthic invertebrates (~38 per trawl), representing 61 taxa, were collected during 2009 (Table 6.4, Appendix E.5). As in previous years, the asteroid *Astropecten verrilli*

Table 6.4

Species of megabenthic invertebrates collected in 28 trawls in the SBOO region during 2009. PA = percent abundance; FO = frequency of occurrence; MAH = mean abundance per haul; MAO = mean abundance per occurrence.

Species	PA	FO	MAH	MAO	Species	PA	FO	MAH	MAO
Astropecten verrilli	31	75	12	16	*Crossata californica*	<1	11	<1	1
Ophiothrix spiculata	15	25	6	22	*Pteropurpura festiva*	<1	11	<1	1
Ophiura luetkenii	7	11	3	26	*Randallia ornata*	<1	11	<1	1
Dendraster terminalis	6	32	2	7	*Crangon alba*	<1	7	<1	2
Crangon nigromaculata	5	39	2	5	*Halosydna latior*	<1	7	<1	2
Heptacarpus stimpsoni	3	11	1	11	*Aglaja ocelligera*	<1	7	<1	1
Orthopagurus minimus	3	7	1	16	*Armina californica*	<1	7	<1	1
Acanthodoris brunnea	3	32	1	3	*Megastraea turbanica*	<1	7	<1	1
Pisaster brevispinus	3	46	1	2	*Megasurcula carpenteriana*	<1	7	<1	1
Pyromaia tuberculata	2	39	1	2	*Metacarcinus gracilis*	<1	7	<1	1
Philine auriformis	2	18	1	4	*Portunus xantusii*	<1	7	<1	1
Platymera gaudichaudii	1	29	1	2	*Sicyonia penicillata*	<1	7	<1	1
Heterocrypta occidentalis	1	25	<1	2	*Thesea* sp B	<1	7	<1	1
Sicyonia ingentis	1	14	<1	3	*Calliostoma gloriosum*	<1	4	<1	2
Lytechinus pictus	1	25	<1	2	*Acanthoptilum* sp	<1	4	<1	1
Octopus rubescens	1	29	<1	1	*Amphissa undata*	<1	4	<1	1
Hemisquilla californiensis	1	25	<1	1	*Aphrodita refulgida*	<1	4	<1	1
Elthusa vulgaris	1	21	<1	1	*Calliostoma annulatum*	<1	4	<1	1
Kelletia kelletii	1	21	<1	1	*Calliostoma tricolor*	<1	4	<1	1
Flabellina iodinea	1	14	<1	2	*Calliostoma turbinum*	<1	4	<1	1
Heptacarpus fuscimaculatus	1	4	<1	8	*Cancer antennarius*	<1	4	<1	1
Acanthodoris rhodoceras	1	11	<1	2	*Conus californicus*	<1	4	<1	1
Aphrodita armifera	1	7	<1	3	*Harmothoe imbricata* complex	<1	4	<1	1
Pandalus danae	1	7	<1	3	*Luidia asthenosoma*	<1	4	<1	1
Melibe leonina	1	4	<1	6	*Lysmata californica*	<1	4	<1	1
Loxorhynchus grandis	<1	14	<1	1	*Metacarcinus anthonyi*	<1	4	<1	1
Nassarius perpinguis	<1	11	<1	2	*Pinnixa franciscana*	<1	4	<1	1
Pagurus spilocarpus	<1	14	<1	1	*Pleurobranchaea californica*	<1	4	<1	1
Dendronotus iris	<1	11	<1	1	*Romaleon jordani*	<1	4	<1	1
Podochela hemphillii	<1	11	<1	1	*Spirontocaris prionota*	<1	4	<1	1
Heptacarpus palpator	<1	7	<1	2					

was the most abundant and most frequently captured species. This sea star was captured in 75% of the trawls and accounted for 31% of the total invertebrate abundance. The remaining taxa occurred infrequently, with only five species occurring in 32% or more of the hauls. With the exception of *A. verrilli*, all of the species collected averaged no more than six individuals per haul.

Megabenthic invertebrate community structure varied among stations and between surveys during the year (Table 6.5). Species richness ranged from 3 to 20 species per haul, diversity (H') values ranged from 0.3 to 2.5 per haul, and total abundance ranged from 3 to 129 individuals per haul. The biggest hauls occurred at stations SD15 and SD21, and were characterized by large numbers of various species collected at these stations during each survey (Appendix E.6). For example, the brittle star *Ophiothrix spiculata* dominated the hauls taken at SD21 in January and April, whereas *A. verrilli* dominated the hauls taken at SD15 in April and October, the sand dollar *Dendraster terminalis* dominated SD15 in April and the brittlestar *Ophiura luetkeni* dominated SD15 in July. Although biomass was also somewhat variable (0.1–3.0 kg), the highest values generally corresponded to the collection of relatively large sea stars or crabs.

Table 6.5

Summary of megabenthic invertebrate community parameters for SBOO stations sampled during 2009. Data are included for species richness (number of species), abundance (number of individuals), diversity (H'), and biomass (kg, wet weight); SD = standard deviation.

Station	Jan	Apr	Jul	Oct	Annual Mean	Annual SD
Species Richness						
SD15	12	8	8	5	8	3
SD16	5	6	7	5	6	1
SD17	4	11	7	9	8	3
SD18	6	8	9	20	11	6
SD19	4	7	9	11	8	3
SD20	3	3	5	8	5	2
SD21	9	14	15	7	11	4
Survey Mean	6	8	9	9		
Survey SD	3	4	3	5		
Diversity						
SD15	1.92	0.97	0.67	0.28	0.96	0.70
SD16	1.23	1.23	1.83	1.13	1.35	0.32
SD17	1.33	2.21	1.69	1.46	1.67	0.39
SD18	1.74	1.35	2.15	2.41	1.91	0.47
SD19	1.21	1.35	1.90	2.11	1.64	0.43
SD20	1.10	0.33	1.55	1.24	1.06	0.52
SD21	0.69	1.85	2.45	1.83	1.71	0.74
Survey Mean	1.32	1.33	1.75	1.50		
Survey SD	0.41	0.60	0.56	0.71		

Station	Jan	Apr	Jul	Oct	Annual Mean	Annual SD
Abundance						
SD15	46	109	84	129	92	36
SD16	10	14	9	14	12	3
SD17	5	24	13	35	19	13
SD18	9	24	11	99	36	43
SD19	8	24	22	28	21	9
SD20	3	37	7	22	17	16
SD21	118	108	33	10	67	54
Survey Mean	28	49	26	48		
Survey SD	42	41	27	47		
Biomass						
SD15	0.1	0.5	0.9	0.7	0.5	0.3
SD16	0.1	1.2	1.1	0.4	0.7	0.5
SD17	0.1	1.0	0.1	0.1	0.3	0.5
SD18	0.2	0.4	0.8	3.0	1.1	1.3
SD19	0.5	1.8	2.0	0.5	1.2	0.8
SD20	0.3	0.5	0.4	0.6	0.4	0.1
SD21	2.9	2.6	2.6	1.1	2.3	0.8
Survey Mean	0.6	1.1	1.1	0.9		
Survey SD	1.0	0.8	0.9	1.0		

Variations in megabenthic invertebrate community structure in the South Bay region generally reflect changes in species abundance (Figure 6.5, 6.6). Although species richness has varied little over the years (e.g., 4–14 species/trawl), annual abundance values have averaged between 7 and 273 individuals per haul. These large differences have typically been due to fluctuations in populations of several dominant species, including *A. verrilli*, the sea urchin *Lytechinus pictus*, *D. terminalis,* and the shrimp *Crangon nigromaculata* (Figure 6.6). For example, trawls at station SD15 have had the highest average abundance compared to the other stations for 9 out of 15 years due to relatively large populations of *A. verrilli*, *L. pictus,* and *D. terminalis*. In addition, the high abundances recorded at station SD17 in 1996 were due to large hauls of *L. pictus*. None of the observed variability in the invertebrate communities appear related to the South Bay outfall.

Summary and Conclusions

As in previous years, speckled sanddabs continued to dominate fish assemblages surrounding the SBOO during 2009. This species occurred at all stations and accounted for 38% of the total catch. Other characteristic, but less abundant species included the California lizardfish, yellowchin sculpin, roughback sculpin, longfin sanddab, hornyhead turbot, California tonguefish, and plainfin midshipman. Most of these common fishes were relatively small, averaging less than 20 cm in length. Although the composition and structure of the fish assemblages varied among stations, these differences were mostly due to variations in speckled sanddab, California lizardfish, and yellowchin sculpin populations.

Assemblages of relatively large (megabenthic) invertebrates in the region were similarly dominated by

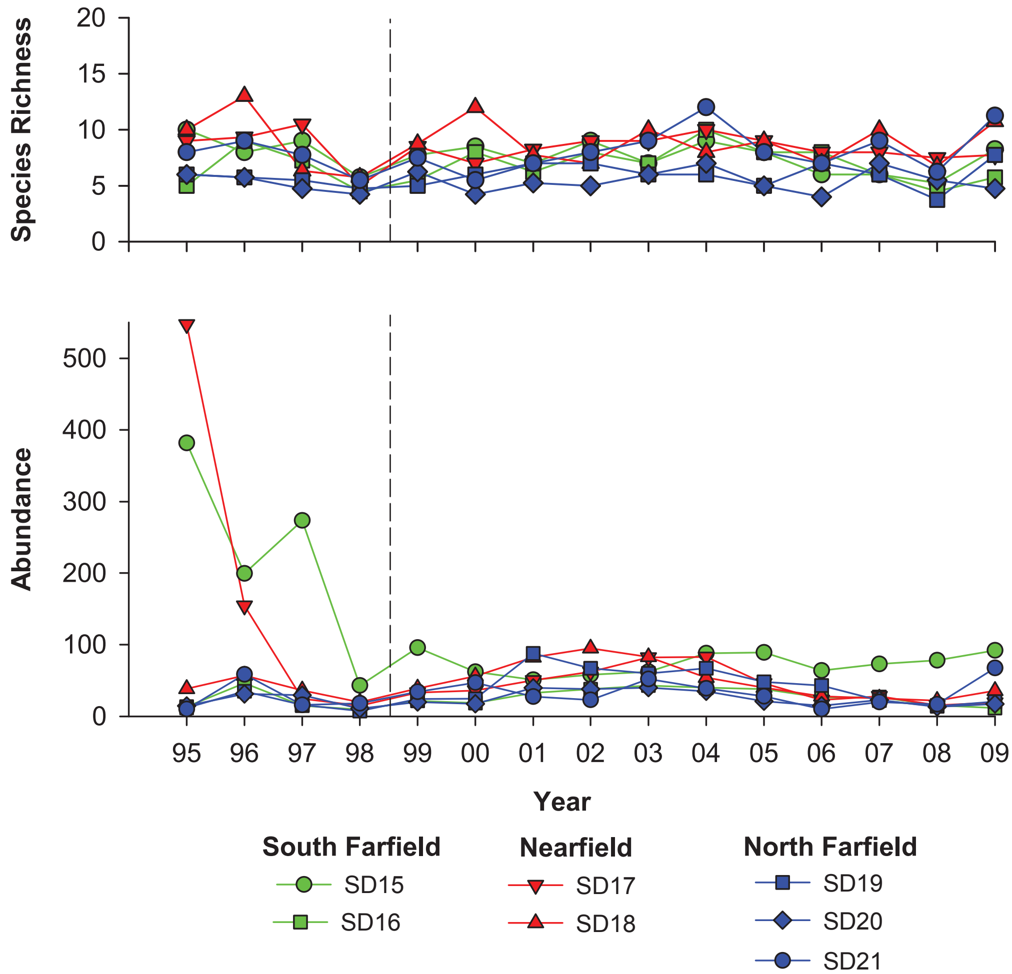


Figure 6.5
Species richness (number of species) and abundance (number of individuals) of megabenthic invertebrates collected in the SBOO region from 1995 through 2009. Data are annual means; $n=2$ in 1995 and $n=4$ between 1996–2009. Dashed line represents initiation of wastewater discharge.

one prominent species, the sea star *Astropecten verrilli*. Variations in community structure of the trawl-caught invertebrates generally reflect changes in the abundance of this sea star, as well as other dominant species such the sand dollar *Dendraster terminalis,* and the brittle stars *Ophiothrix spiculata* and *Ophiura luetkeni*.

Overall, results of the 2009 trawl surveys provide no evidence that wastewater discharged through the SBOO has affected either demersal fish or megabenthic invertebrate communities in the region. Although highly variable, patterns in the abundance and distribution of species were similar at stations located near the outfall and farther away, with no discernible changes in the region following the onset of the SBOO wastewater discharge in January 1999. Instead, the high degree of variability in these communities observed during 2009 was similar to those that occurred in previous years (e.g., City of San Diego 2006–2009), including the period before initiation of wastewater discharge (City of San Diego 2000). In addition, the low species richness and abundances of fish and invertebrates found during the 2009 surveys are consistent with what is expected for the relatively shallow, sandy habitats in which the SBOO stations are located (see Allen et al. 1998, 2002, 2007). Changes in these communities appear to be more likely due to natural factors such as changes in ocean water temperatures associated with large-scale oceanographic events (e.g., El Niño or La Niña) or to the mobile nature of many of the resident species collected. Finally, the absence of disease or other physical abnormalities in local fishes suggests that populations in the area continue to be healthy.

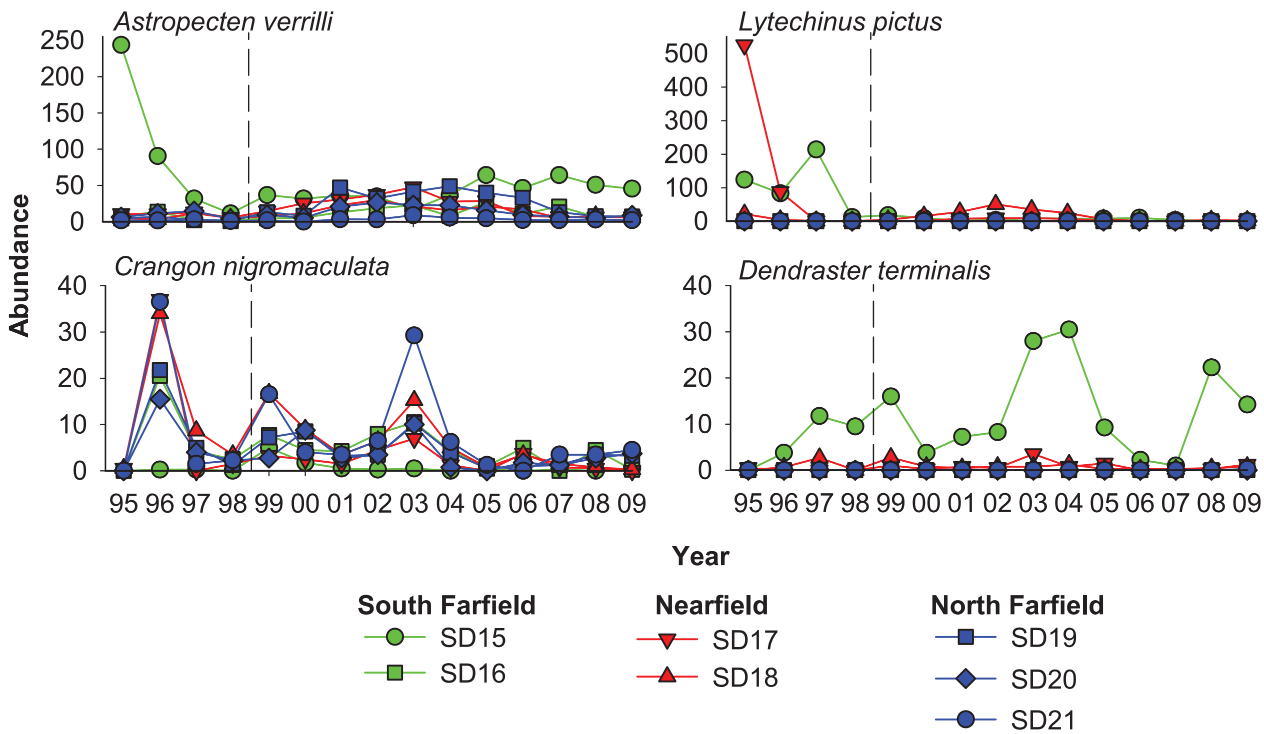


Figure 6.6
Abundance (number of individuals) of the four most abundant megabenthic species collected in the SBOO region from 1995 through 2009. Data are annual means; $n = 2$ in 1995 and $n = 4$ between 1996–2009. Dashed line represents initiation of wastewater discharge.

Literature Cited

Allen, M.J. (1982). Functional Structure of Soft-bottom Fish Communities of the Southern California Shelf. Ph.D. dissertation. University of California, San Diego. La Jolla, CA.

Allen, M.J. (2005). The check list of trawl-caught fishes for Southern California from depths of 2–1000 m. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., S.L. Moore, K.C. Schiff, S.B. Weisberg, D. Diener, J.K. Stull, A. Groce, J. Mubarak, C.L. Tang, and R. Gartman. (1998). Southern California Bight 1994 Pilot Project: Chapter V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Westminster, CA.

Allen, M.J., T. Mikel, D. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S. Walther, G. Deets, C. Cash, S. Watts, D.J. Pondella II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce, and J.L. Armstrong. (2007). Southern California Bight 2003 Regional Monitoring Program: IV. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project. Costa Mesa, CA.

Brusca, R.C. (1978). Studies on the cymothoid fish symbionts of the eastern Pacific (Crustacea: Cymothoidae). II. Systematics and biology of *Livoneca vulgaris* Stimpson 1857. Occassional Papers of the Allan Hancock Foundation. (New Series), 2: 1–19.

Brusca, R.C. (1981). A monograph on the Isopoda Cymothoidae (Crustacea) of the eastern Pacific. Zoological Journal of the Linnean Society, 73: 117–199.

City of San Diego. (2000). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2009). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2008. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R. and R.N. Gorley. (2006). Primer v6: User Manual/Tutorial. PRIMER-E: Plymouth.

Cross, J.N., J.N. Roney, and G.S. Kleppel. (1985). Fish food habitats along a pollution gradient. California Fish and Game, 71: 28–39.

Cross, J.N. and L.G. Allen. (1993). Chapter 9. Fishes. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 459–540.

Eschmeyer, W.N. and E.S. Herald. (1998). A Field Guide to Pacific Coast Fishes of North America. Houghton and Mifflin Company, New York.

Helvey, M. and R.W. Smith. (1985). Influence of habitat structure on the fish assemblages associated with two cooling-water intake structures in southern California. Bulletin of Marine Science, 37: 189–199.

Karinen, J.B., B.L. Wing, and R.R. Straty. (1985). Records and sightings of fish and invertebrates in the eastern Gulf of Alaska and oceanic phenomena related to the 1983 El Niño event. In: W.S. Wooster, and D.L. Fluharty (eds.). El Niño North: El Niño Effects in the Eastern Subarctic Pacific Ocean. Washington Sea Grant Program. p 253–267.

Murawski, S.A. (1993). Climate change and marine fish distribution: forecasting from historical analogy. Transactions of the American Fisheries Society, 122: 647–658.

[SCAMIT] The Southern California Association of Marine Invertebrate Taxonomists. (2008). A taxonomic listing of soft bottom macro- and megabenthic invertebrates from infaunal and epibenthic monitoring programs in the Southern California Bight; Edition 5. SCAMIT. San Pedro, CA.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology 18: 63–80.

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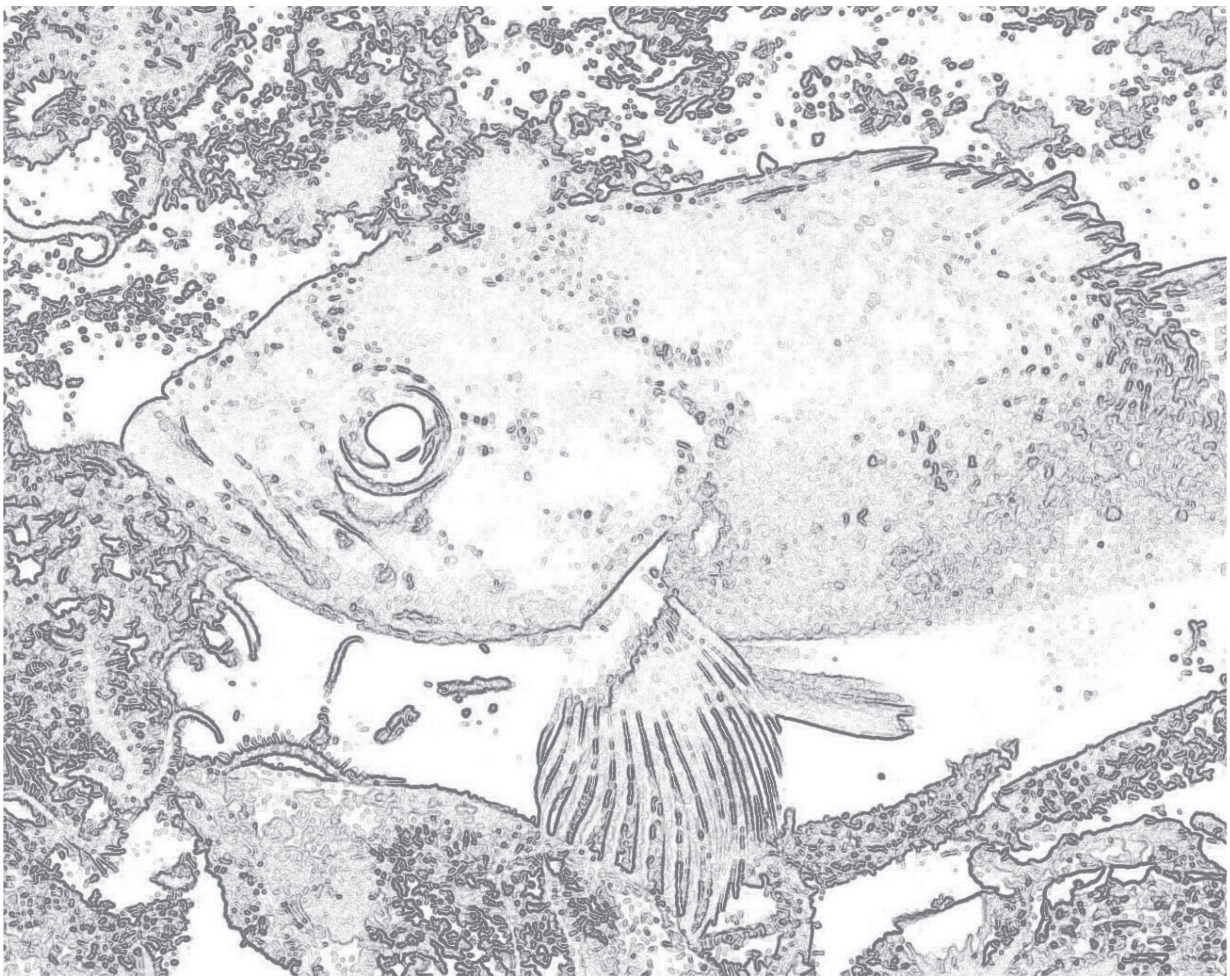
Chapter 7
Bioaccumulation of Contaminants in Fish Tissues



Chapter 7. Bioaccumulation of Contaminants in Fish Tissues

Introduction

Bottom dwelling (i.e., demersal) fishes are collected as part of the South Bay Ocean Outfall (SBOO) monitoring program to assess the accumulation of contaminants in their tissues. Bioaccumulation of contaminants in fish occurs through the biological uptake and retention of chemical contaminants derived via various exposure pathways (U.S. EPA 2000). The main exposure routes for demersal fishes include uptake of dissolved chemicals in seawater and the ingestion and assimilation of pollutants contained in different food sources (Rand 1995). Because of their proximity to seafloor sediments, these fish may also accumulate contaminants through ingestion of suspended particulates or sediments that contain pollutants. For this reason, the levels of many contaminants in the tissues of demersal fish are often related to those found in the environment (Schiff and Allen 1997), thus making these types of assessments useful in biomonitoring programs.

The bioaccumulation portion of the South Bay monitoring program consists of two components: (1) liver tissues are analyzed for trawl-caught fishes; (2) muscle tissues are analyzed for fishes collected by hook and line (rig fishing). Species of fish collected by trawling activities (see Chapter 6) are representative of the general demersal fish community, and certain species are targeted based on their prevalence in the community and therefore ecological significance. The chemical analysis of liver tissues in these fish is especially important for assessing population effects because this is the organ where contaminants typically concentrate (i.e., bioaccumulate). In contrast, fishes targeted for capture by rig fishing represent species that are characteristic of a typical sport fisher's catch, and are therefore considered of recreational and commercial importance and more directly relevant to human health concerns. Consequently, muscle tissue is analyzed from these fishes because it is the tissue most often consumed by humans, and therefore the results may have public health implications.

This chapter presents the results of all tissue analyses that were performed on fishes collected in the SBOO region during 2009. All liver and muscle samples were analyzed for contaminants as specified in the NPDES discharge permits that govern the SBOO monitoring program (see Chapter 1). Most of these contaminants are also sampled for the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program. NOAA initiated this program to detect and monitor changes in the environmental quality of the nation's estuarine and coastal waters by tracking contaminants thought to be of environmental concern (Lauenstein and Cantillo 1993).

Materials and Methods

Field Collection

Fishes were collected during April and October of 2009 at seven trawl and two rig fishing stations (Figure 7.1). California scorpionfish (*Scorpaena guttata*), English sole (*Parophrys vetulus*), hornyhead turbot (*Pleuronichthys verticalis*), and longfin sanddab (*Citharichthys xanthostigma*) were collected for analysis of liver tissues from the trawling stations, while California scorpionfish, brown rockfish (*Sebastes auriculatus*), calico rockfish (*Sebastes dallii*), copper rockfish (*Sebastes caurinus*), vermilion rockfish (*Sebastes miniatus*), and yellowtail rockfish (*Sebastes flavidus*) were collected for analysis of muscle tissues at the two rig fishing stations (see Table 7.1). All trawl-caught fishes were collected following City of San Diego guidelines (see Chapter 6 for a description of collection methods). Efforts to collect the targeted fish species at the trawl stations were limited to five 10-minute (bottom time) trawls per site. Fishes collected at the two rig fishing stations were caught within 1 km of the station location using standard rod and reel procedures; fishing effort was limited to 5 hours at each of these stations. Occasionally, insufficient numbers of the target species were obtained despite this effort, thus resulting in reduced number of composite samples at a particular station.

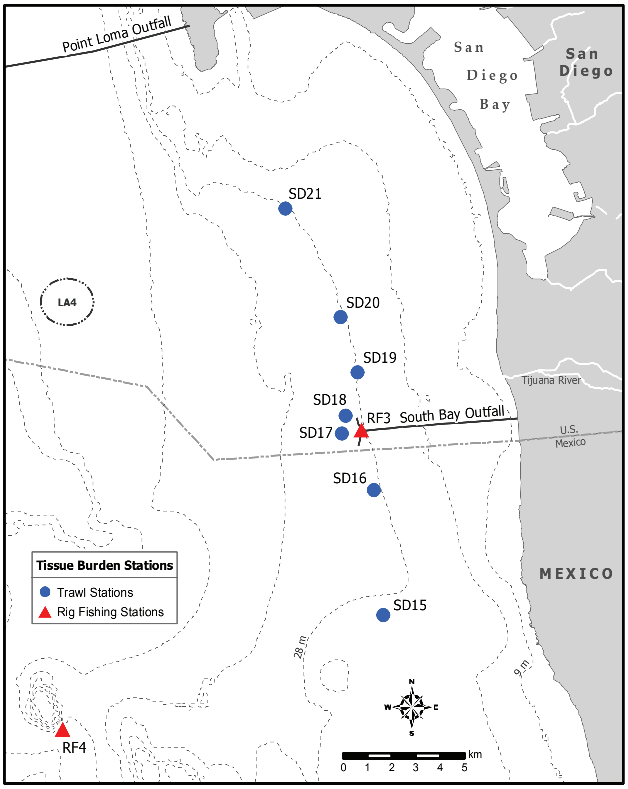


Figure 7.1

Otter trawl and rig fishing stations for the South Bay Ocean Outfall Monitoring Program.

In order to facilitate the collection of sufficient tissue for subsequent chemical analysis, only fish ≥13 cm in standard length were retained. These fish were sorted into no more than three composite samples per station, each containing a minimum of three individuals. Composite samples were typically made up of a single species; the only exceptions were samples that consisted of mixed species of rockfish as indicated in Table 7.1. All fish collected were wrapped in aluminum foil, labeled, sealed in re-sealable plastic bags, placed on dry ice, and then transported to the City's Marine Biology Laboratory where they were held in the freezer at -80°C until dissection and tissue processing.

Tissue Processing and Chemical Analyses

All dissections were performed according to standard techniques for tissue analysis. A brief summary follows, but see City of San Diego (2004) for additional details. Prior to dissection, each fish was partially defrosted and then cleaned with a paper towel to remove loose scales and excess mucus. The standard length (cm) and weight (g) of each fish were recorded (Appendix F.1). Dissections were carried out on Teflon® pads that were cleaned between samples. The tissues (liver or muscle) from each dissected fish were then placed in separate glass jars for each composite sample, sealed, labeled, and stored in a freezer at -20°C prior to chemical analyses. All samples were subsequently delivered to the City's Wastewater Chemistry Services Laboratory for analysis within 10 days of dissection.

The chemical constituents analyzed for each tissue sample were measured on a wet weight basis, and included trace metals, chlorinated pesticides, polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) (see Appendix F.2). Metals were measured in units of mg/kg and are expressed herein as parts per million (ppm), while pesticides, PCBs, and PAHs were measured as µg/kg and expressed as parts per billion (ppb). This report includes estimated values for some parameters determined to be present in a sample with high confidence (i.e., peaks confirmed by mass-spectrometry), but that otherwise occurred at levels below the method detection limit (MDL). A detailed description of the protocols for chemical analyses is available in City of San Diego (2010).

Data Analyses

Data summaries included detection rates (i.e., number of reported values/number of samples), minimum, maximum, and mean detected values of each parameter by species. Totals for DDT, PCBs, HCH, chlordane, and PAHs were calculated as the sum of the detected constituents (i.e., total PCB = sum of all congeners detected). The detected values for each individual constituent are listed in Appendix F.3. In addition, the distribution of frequently detected contaminants in fishes collected in the SBOO region was assessed by

Table 7.1
Species of fish collected for tissue analysis at each SBOO trawl and rig fishing station during April and October 2009.

Survey	Station	Composite 1	Composite 2	Composite 3
April 2009	RF3	Brown rockfish	Brown rockfish	Mixed rockfish [a]
	RF4	California scorpionfish	California scorpionfish	California scorpionfish
	SD15	English sole	Hornyhead turbot	No sample [c]
	SD16	Longfin sanddab	Hornyhead turbot [b]	No sample [c]
	SD17	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD18	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD19	Longfin sanddab [b]	Hornyhead turbot [b]	No sample [c]
	SD20	No sample [c]	No sample [c]	No sample [c]
	SD21	Longfin sanddab	Longfin sanddab	Hornyhead turbot
October 2009	RF3	Brown rockfish	Brown rockfish	Mixed rockfish [d]
	RF4	California scorpionfish	California scorpionfish	California scorpionfish
	SD15	Hornyhead turbot [b]	No sample [c]	No sample [c]
	SD16	Hornyhead turbot	Longfin sanddab	Longfin sanddab
	SD17	Hornyhead turbot	California scorpionfish	Hornyhead turbot
	SD18	Hornyhead turbot	Hornyhead turbot	California scorpionfish
	SD19	Longfin sanddab	Longfin sanddab	Longfin sanddab
	SD20	Longfin sanddab	Longfin sanddab [e]	Hornyhead turbot
	SD21	Hornyhead turbot	Hornyhead turbot	California scorpionfish

[a] Includes vermilion, calico, copper, and yellowtail rockfish; [b] Not enough tissue to analyze metals; [c] Insufficient fish collected (see text); [d] Includes brown and vermilion rockfish; [e] PAH failed QC, not enough tissue to re-analyze.

comparing concentrations in fishes collected at "nearfield" stations located within a kilometer of the SBOO (SD17, SD18, RF3) to those from "farfield" stations located farther away to the south (SD15, SD16), north (SD19–SD21), and west (RF4). When available, concentrations were also compared to values detected during the pre-discharge period (1995–1998). Because concentrations of contaminants varied so much among the species collected, only intra-species comparisons were used for these evaluations.

Finally, contaminant concentrations found in the muscle tissues of fishes collected as part of the SBOO monitoring program were compared to state, national, and international limits and standards to address human health concerns. These include: (1) the California Office of Environmental Health Hazard Assessment (OEHHA), which has developed fish contaminant goals for chlordane, DDT, methylmercury, PCBs, and selenium (Klasing and Brodberg 2008); (2) the United States Food and Drug Administration (U.S. FDA), which has set limits on the amount of mercury, total DDT, and chlordane in seafood that is to be sold for human consumption (see Mearns et al. 1991); (3) international standards for acceptable concentrations of various metals and DDT (see Mearns et al. 1991).

Results and Discussion

Contaminants in Trawl-Caught Fishes

Metals

Thirteen metals occurred in ≥70% of the liver samples analyzed from trawl-caught fishes in 2009, including aluminum, arsenic, barium, cadmium, chromium, copper, iron, manganese, mercury, selenium, silver, tin, and zinc (Table 7.2). Another four metals (antimony, beryllium, lead, thallium) were also detected, but less frequently at rates between 3–40%. Nickel was not detected in any of the liver samples collected during 2009. Tissue concentrations of most metals were <30 ppm over all species. Exceptions occurred for aluminum, iron, and zinc, which all had concentrations >60 ppm in at least one sample. Several metals occurred in quantities that varied greatly among the different species of fish. For example, the highest values of beryllium, chromium, copper, iron, mercury, silver, thallium, and zinc occurred in samples of California scorpionfish. In contrast, the highest values of aluminum, antimony, barium, lead, manganese, selenium, and tin occurred in samples of longfin sanddab. These differences are not unexpected, as it has been well documented that the bioaccumulation of contaminants can vary greatly between fish species due to differences in physiology and life history (see Groce 2002 and references therein).

Intra-species comparisons between nearfield and farfield stations suggest that there was no clear relationship between contaminant loads in fish liver tissues and proximity to the outfall (Figure 7.2). Contaminant concentrations were generally similar among stations and most samples had levels of metals close to or below the maximum levels detected in the same species prior to discharge. Exceptions occurred for aluminum, arsenic, cadmium, copper, manganese, mercury, and zinc, which had between 1 and 9 samples (out of 30 total) that exceeded pre-discharge maximums. These relatively high concentrations occurred throughout the region and showed no pattern relative to the outfall.

Pesticides

Several chlorinated pesticides were detected in fish liver tissues during the 2009 trawl surveys (Table 7.3). DDT was found in every tissue sample with total DDT concentrations ranging from 26 to 2802 ppb. The most frequently detected DDT constituent was p,p-DDE, which was found in 100% of these samples at concentrations up to 2700 ppb (Appendix F.3). Other DDT constituents detected frequently (i.e., >50% of the samples) included o,p-DDE and p,p-DDD. Other pesticides detected in fish tissues during the past year included hexachlorobenzene (HCB) in 65% of the samples at concentrations up to 4.7 ppb, chlordane in 9% of the samples at concentrations up to about 20 ppb, and endrin in 6% of the samples at concentrations up to 210 ppb. Total chlordane consisted of trans-nonachlor in two samples of California scorpionfish, whereas it consisted of alpha and gamma-chlordane in a single sample of hornyhead turbot (Appendix F.3).

Most pesticide concentrations were near or below the maximum levels detected in the same species prior to wastewater discharge (Figure 7.3). Only one sample of hornyhead turbot collected from station SD20 had values of total DDT that exceeded the pre-discharge maximum. In addition, no clear relationship could be determined between concentrations of these pesticides in fish tissues and proximity to the outfall (Figure 7.3), or with lipid content, or with the size of the fishes (length or weight) used in each composite.

PAHs and PCBs

PAHs were not detected in fish liver samples during 2009. In contrast, PCBs occurred in every tissue sample (Table 7.3). PCB 153/168 was the most frequently detected congener in liver tissues as it was found in every sample; other frequently detected congeners (i.e., >70%) included PCB 99, PCB 101, PCB 118, PCB 138, PCB 180, and PCB 187 (Appendix F.3). Total PCB concentrations were highly variable in South Bay fish tissues, ranging from 2.4 to 841.9 ppb (Table 7.3). These concentrations were substantially less than pre-discharge values, with no clear relationship with proximity to the outfall (Figure 7.3), lipid content, or with the size of the fishes used in each composite.

Contaminants in Fishes Collected by Rig Fishing

Aluminum, arsenic, barium, chromium, copper, iron, mercury, selenium, and zinc occurred in ≥75% of the muscle tissue samples collected from the two rig fishing stations in 2009 (Table 7.4).

Table 7.2

Summary of metals in liver tissues of fishes collected at SBOO trawl stations during 2009. Data include the number of detected values (*n*), as well as minimum (Min), maximum (Max) and mean detected concentrations for each species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses. See Appendix F.2 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
California scorpionfish																		
n (out of 3)	3	0	3	2	1	3	1	3	3	1	3	3	0	3	3	1	2	3
Min	4.8	—	0.8	0.048	0.014	2.61	0.439	13.0	174	0.112	0.29	0.276	—	0.57	0.181	1.58	0.36	95.5
Max	11.4	—	1.5	0.093	0.014	3.85	0.439	16.0	233	0.112	0.71	0.441	—	1.12	0.379	1.58	0.44	153.0
Mean	7.2	—	1.1	0.070	0.014	3.27	0.439	14.0	203	0.112	0.50	0.356	—	0.91	0.268	1.58	0.40	118.5
English sole																		
n (out of 1)	1	0	1	1	0	1	1	1	1	1	1	1	0	1	0	0	1	1
Min	18.0	—	28.9	0.175	—	1.98	0.205	9.8	196	0.367	1.90	0.082	—	1.37	—	—	2.66	37.3
Max	18.0	—	28.9	0.175	—	1.98	0.205	9.8	196	0.367	1.90	0.082	—	1.37	—	—	2.66	37.3
Mean	18.0	—	28.9	0.175	—	1.98	0.205	9.8	196	0.367	1.90	0.082	—	1.37	—	—	2.66	37.3
Hornyhead turbot																		
n (out of 10)	7	0	10	6	0	10	6	10	10	0	10	10	0	10	8	0	10	10
Min	3.4	—	2.3	0.037	—	2.17	0.107	4.1	40	—	0.81	0.064	—	0.50	0.050	—	0.23	23.0
Max	28.5	—	8.1	0.175	—	8.24	0.303	8.8	106	—	1.94	0.202	—	1.58	0.276	—	1.69	97.4
Mean	9.4	—	4.0	0.086	—	5.23	0.176	6.6	59	—	1.24	0.128	—	0.90	0.144	—	0.59	49.6
Longfin sanddab																		
n (out of 16)	16	6	16	15	1	16	13	16	16	10	16	16	0	16	12	0	14	16
Min	4.3	0.207	2.6	0.032	0.009	1.22	0.072	4.2	35	0.121	0.68	0.042	—	1.02	0.065	—	0.23	13.9
Max	60.7	0.811	17.6	1.520	0.009	6.20	0.406	12.4	155	1.580	2.65	0.170	—	1.77	0.186	—	3.66	43.6
Mean	19.3	0.382	8.0	0.266	0.009	2.64	0.244	7.9	101	0.398	1.52	0.087	—	1.36	0.121	—	1.87	27.2
All Species:																		
Detection Rate (%)	90	20	100	80	7	100	70	100	100	40	100	100	0	100	77	3	90	100
Max Value	60.7	0.811	28.9	1.520	0.014	8.24	0.439	16.0	233	1.580	2.65	0.441	—	1.77	0.379	1.58	3.66	153.0

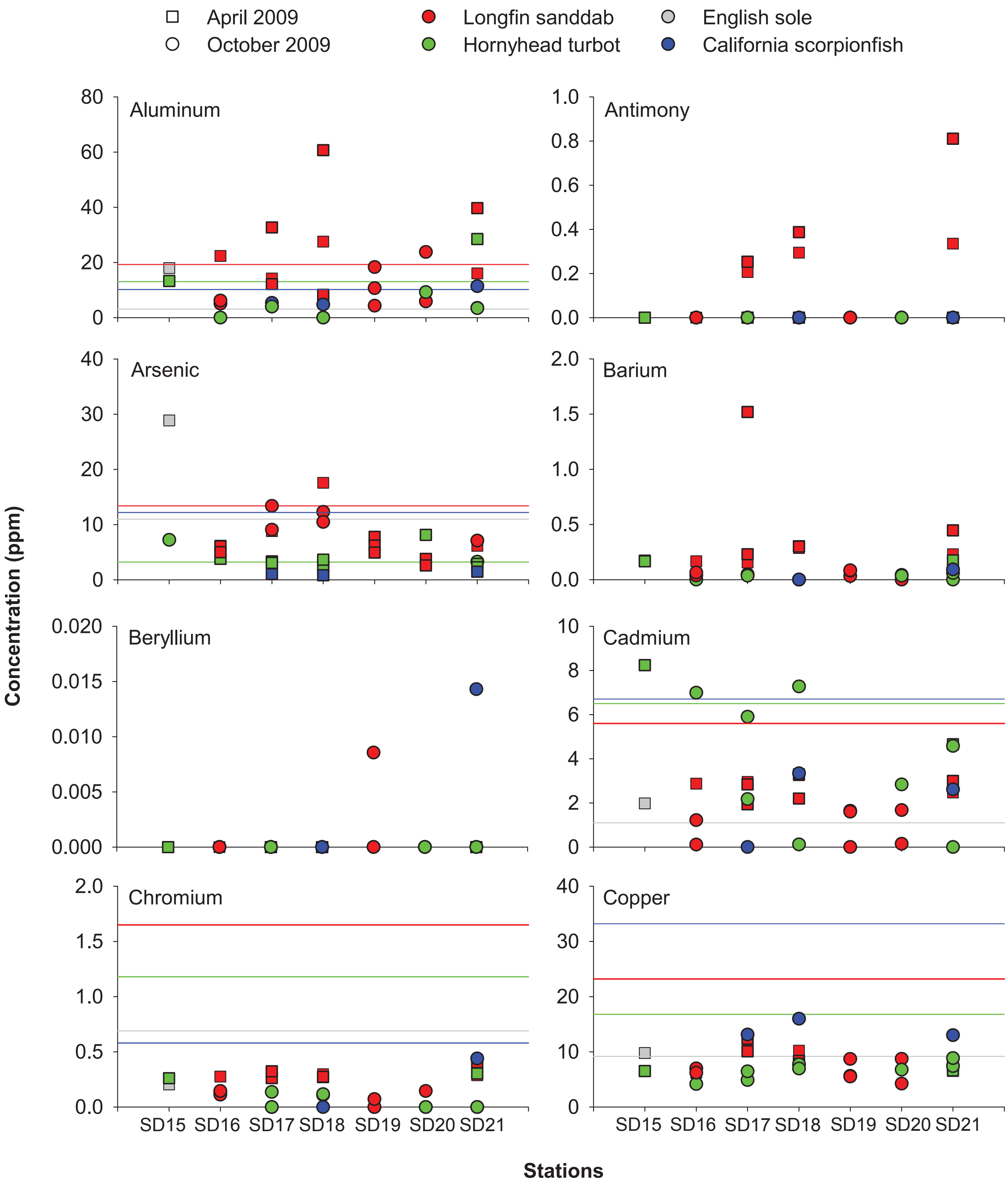


Figure 7.2
Concentrations of frequently detected metals in liver tissues of fishes collected from each SBOO trawl station during 2009. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; antimony, barium, beryllium, and tin were not detected during the pre-discharge period because of substantially higher detection limits. Therefore, no reference lines are present for these contaminants. To differentiate between missing values (i.e., samples that were not collected or not analyzed; see Table 7.1) and non-detects, zeros were added as placed holders for non-detected values.

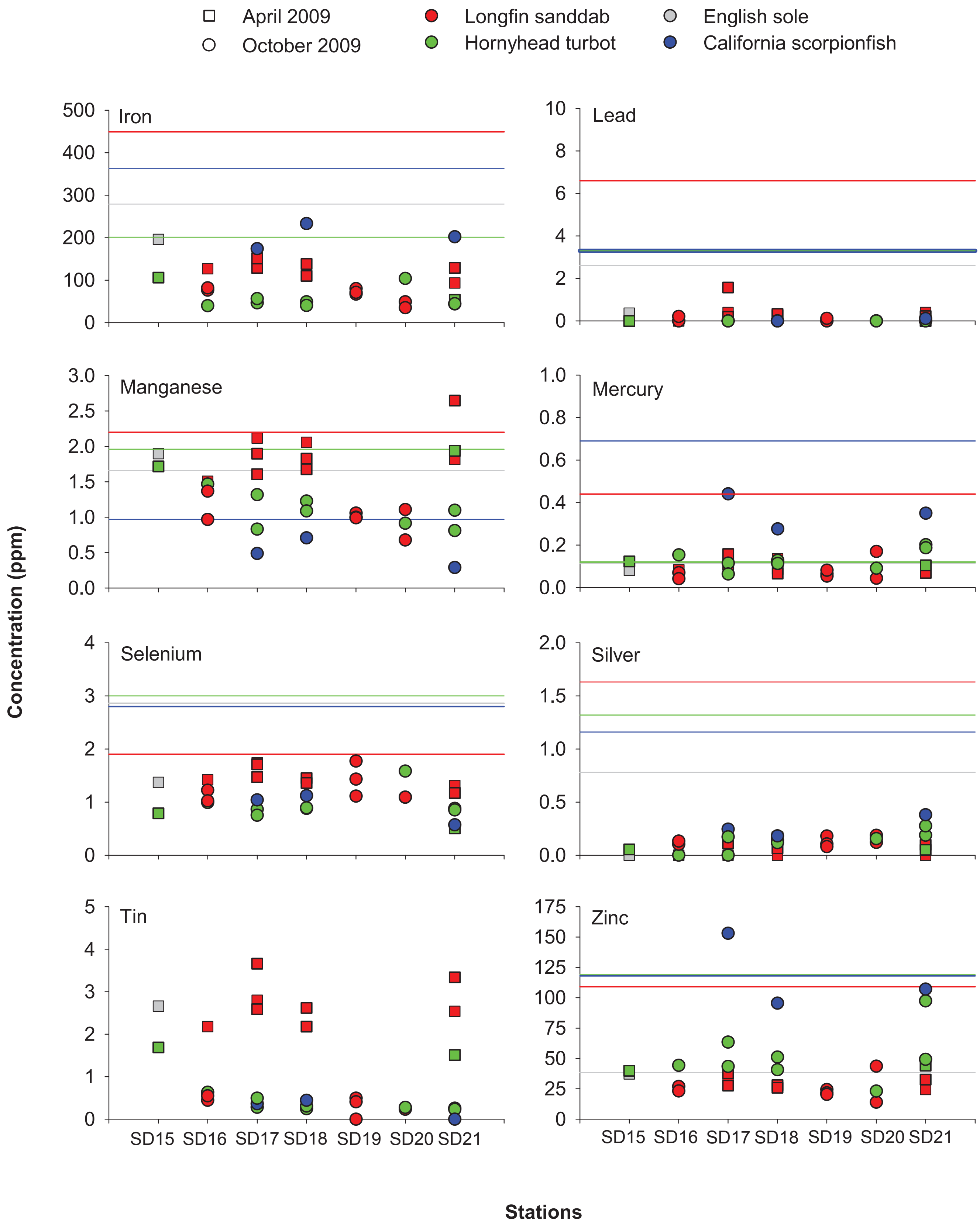


Figure 7.2 *continued*

Manganese and tin were only detected in 50% of the samples, while antimony, beryllium, cadmium, nickel, silver, and thallium were detected in 33% or less of the samples. Lead was never detected. The metals present in the highest concentrations were aluminum (up to 16.4 ppm), zinc (up to 6.7 ppm), iron (up to 5.8 ppm), and arsenic (up to 3.5 ppm).

Total DDT, comprised exclusively of p,p-DDE, was detected in 100% of the muscle samples, while the pesticide HCB and PCBs were detected in 8 and 92% of the samples, respectively (Table 7.5). The PCB congener PCB 153/168 was also found in 92% of the samples; the only other PCB congeners measured in the muscle tissue samples were PCB 99, PCB 101, PCB 118, PCB 138, and PCB 187. Concentrations of these contaminants ranged from < 1 ppb for HCB to 8.0 ppb for total DDT.

Of the contaminants detected in muscle tissues during 2009, only the metals arsenic and selenium occurred in concentrations higher than median international standards, while mercury (as a proxy for methylmercury) exceeded the OEHHA fish contaminant goal. Exceedances for arsenic occurred in both California scorpionfish and mixed rockfish muscle samples, while the exeedances for mercury and selenium occurred only in scorpionfish.

In addition to addressing health concerns, spatial patterns were analyzed for total DDT and total PCB, as well as for all metals that occurred frequently in muscle tissue samples (Figure 7.4). Overall, concentrations of DDT, PCB, and various metals in the muscle tissues of fishes captured at rig fishing stations RF3 and RF4 were fairly similar, which suggests that there was no relationship with proximity to the outfall. However, comparisons of contaminant loads in fishes from these stations should be considered with caution since different species of fish were collected at the two sites, and the bioaccumulation of contaminants may differ between species because of differences in physiology, diet, and exposure to contaminant sources due to migration habits and/or other large scale movements. This potential problem may be minimal in the South Bay region as all fish specimens sampled in 2009 have similar life histories (i.e., bottom dwelling tertiary carnivores), and are therefore likely to have similar mechanisms of exposure to and uptake of contaminants (e.g., direct contact with sediments, similar food sources). However, species such as those reported herein are

Table 7.3

Summary of chlorinated pesticides, total PCB, and lipids in liver tissues of fishes collected at SBOO trawl stations during 2009. Data include the number of detected values (*n*), as well as minimum (Min), maximum (Max), and mean detected concentrations for each species. HCB = hexachlorobenzene; tChl = total chlordane; tDDT = total DDT; End. = endrin; tPCB = total PCB; Lip. = lipids. Data are expressed in parts per billion (ppb) for all parameters except lipids, which are presented as percent weight (% wt); the number of samples per species is indicated in parentheses; See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total chlordane, total DDT, and total PCB.

	Pesticides					
	HCB	**tChl**	**tDDT**	**End.**	**tPCB**	**Lip.**
California scorpionfish						
n (out of 3)	3	2	3	0	3	3
Min	1.9	14.0	719	—	403.7	12
Max	3.3	15.0	1004	—	533.2	21
Mean	2.7	14.5	896	—	474.2	17
English sole						
n (out of 1)	0	0	1	0	1	1
Min	—	—	26	—	18.7	4
Max	—	—	26	—	18.7	4
Mean	—	—	26	—	18.7	4
Hornyhead turbot						
n (out of 13)	4	1	13	1	13	13
Min	1.4	20.3	32	98	7.6	3
Max	4.7	20.3	2802	98	841.9	32
Mean	3.0	20.3	294	98	94.2	8
Longfin sanddab						
n (out of 17)	15	0	17	1	17	17
Min	1.7	—	27	210	2.4	6
Max	3.9	—	1184	210	823.9	33
Mean	3.0	—	645	210	423.0	20
All Species:						
Detection Rate (%)	65	9	100	6	100	100
Max Value	4.7	20.3	2802	210	841.9	33

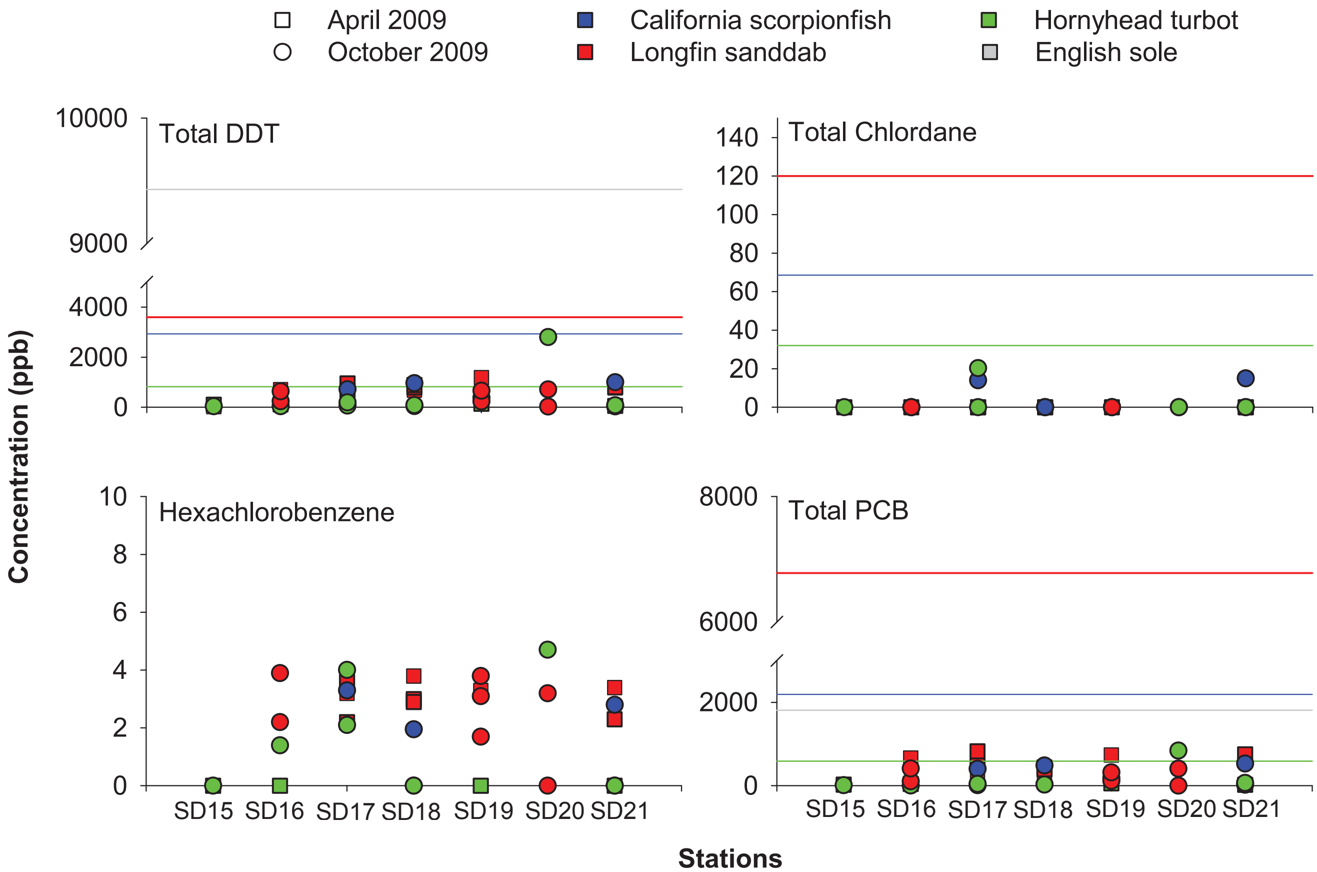


Figure 7.3

Concentrations of frequently detected chlorinated pesticides (total DDT, total chlordane, hexachlorobenzene) and total PCBs in liver tissues of fishes collected from each SBOO trawl station during 2009. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for each species; chlordane and hexachlorobenzene were not detected as frequently during the pre-discharge period because of substantially higher detection limits. Therefore, reference lines for these two contaminants are absent for some or all of the species. To differentiate between missing values (i.e., samples that were not collected or not analyzed; see Table 7.1) and non-detects, zeros were added as placed holders for non-detected values.

known to traverse large areas and may be exposed to contaminants present instead in other locations. For example, it has been previously reported that California scorpionfish tagged in Santa Monica Bay have been recaptured as far south as the Coronado Islands (e.g., Hartmann 1987, Love et al. 1987).

Summary and Conclusions

Several trace metals, the pesticides DDT, HCB, endrin, and various chlordane components, and a combination of PCB congeners were detected in liver tissue samples collected from four different species of fish in the SBOO region during 2009. Many of the same metals, DDT, HCB, and PCBs were also detected in muscle tissues during the year, although less frequently and/or in lower concentrations. Tissue contaminant values ranged widely within and among species and stations. However, all were within the range of values reported previously for the Southern California Bight (SCB) (see Mearns et al. 1991, City of San Diego 1996–2001, Allen et al. 1998). In addition, while some muscle tissue samples from sport fish collected in the area had concentrations of arsenic and selenium above the median international standard for shellfish, and some had concentrations of mercury that exceeded OEHHA fish contaminant goals, concentrations of mercury and DDT were below FDA human consumption limits.

Table 7.4

Summary of metals in muscle tissues of fishes collected at SBOO rig fishing stations during 2009. Data include the number of detected values (*n*), as well as minimum (Min), maximum (Max), and mean detected concentrations for each species. Concentrations are expressed as parts per million (ppm); the number of samples per species is indicated in parentheses. Data are compared to OEHHA fish contaminant goals, U.S. FDA action limits, and median international standards for parameters where these exist. Bold values meet or exceed these standards. See Appendix F.2 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Brown rockfish																		
n (out of 4)	4	0	4	4	0	0	4	4	2	0	2	4	0	4	1	0	2	4
Min	3.7	—	0.7	0.039	—	—	0.112	0.27	4.5	—	0.14	0.104	—	0.16	0.072	—	1.40	2.6
Max	16.4	—	1.0	0.145	—	—	0.180	0.99	5.8	—	0.16	0.164	—	0.28	0.072	—	1.41	6.7
Mean	9.8	—	0.9	0.088	—	—	0.151	0.68	5.2	—	0.15	0.133	—	0.23	0.072	—	1.40	4.4
California scorpionfish																		
n (out of 6)	6	2	6	5	2	1	6	6	5	0	3	6	1	6	2	2	3	6
Min	5.8	0.103	1.1	0.043	0.017	0.063	0.156	0.25	2.4	—	0.05	0.159	0.111	0.25	0.109	0.565	1.41	3.2
Max	14.7	0.111	**3.5**	0.132	0.025	0.063	0.387	1.71	4.5	—	0.19	**0.275**	0.111	**0.34**	0.113	0.652	1.55	5.7
Mean	9.6	0.107	**2.4**	0.085	0.021	0.063	0.243	0.82	3.4	—	0.14	0.191	0.111	0.29	0.111	0.608	1.50	4.4
Mixed rockfish																		
n (out of 2)	2	1	2	2	0	0	2	2	2	0	1	2	0	2	1	0	1	2
Min	5.0	0.218	**1.4**	0.042	—	—	0.165	0.30	2.4	—	0.20	0.120	—	0.19	0.062	—	1.38	2.9
Max	15.3	0.218	**1.4**	0.162	—	—	0.188	1.34	5.0	—	0.20	0.122	—	0.20	0.062	—	1.38	4.5
Mean	10.2	0.218	**1.4**	0.102	—	—	0.176	0.82	3.7	—	0.20	0.121	—	0.20	0.062	—	1.38	3.7
All Species:																		
Detection Rate (%)	100	25	100	92	17	8	100	100	75	0	50	100	8	100	33	17	50	100
Max Value	16.4	0.218	**3.5**	0.162	0.025	0.063	0.387	1.71	5.8	—	0.20	**0.275**	0.111	**0.34**	0.113	0.652	1.55	6.7
OEHHA*												0.22		7.4				
U.S. FDA Action Limit**												1						
Median IS**			1.4				1	20				0.5		0.3			175	70

* From the California Office of Environmental Health Hazard Assessment (OEHHA) (Klasing and Brodberg 2008).

** From Mearns et al. 1991. U.S. FDA mercury action limits and all international standards (IS) are for shellfish, but are often applied to fish.

Table 7.5

Summary of chlorinated pesticides, total PCB, and lipids in muscle tissues of fishes collected at SBOO rig fishing stations during 2009. Data include the number of detected values (*n*), as well as minimum (Min), maximum (Max), and mean detected concentrations for each species. HCB = hexachlorobenzene; tDDT = total DDT; tPCB = total PCB. Values are expressed in parts per billion (ppb) for all parameters except lipids, which are presented as percent weight (% wt); the number of samples per species is indicated in parentheses. Data are compared to OEHHA fish contaminant goals, U.S. FDA action limits, and median international standards for parameters where these exist. Bold values meet or exceed these standards. See Appendix F.2 for MDLs and Appendix F.3 for values of individual constituents summed for total DDT and total PCB.

	Pesticides			
	HCB	tDDT	tPCB	Lipids
Brown rockfish				
n (out of 4)	1	4	4	4
Min	0.3	1.8	0.2	0.08
Max	0.3	5.7	1.7	0.50
Mean	0.3	3.0	0.7	0.23
California scorpionfish				
n (out of 6)	0	6	5	6
Min	—	1.9	0.3	0.10
Max	—	8.0	3.1	1.07
Mean	—	3.9	1.0	0.40
Mixed rockfish				
n (out of 2)	0	2	2	2
Min	—	2.3	0.7	0.05
Max	—	3.7	0.9	0.28
Mean	—	3.0	0.8	0.16
All Species:				
Detection Rate (%)	8	100	92	100
Max Value	0.3	8.0	3.1	1.07
OEHHA*		21	3.6	
U.S. FDA Action Limit**		5000		
Median IS**		5000		

* From the California Office of Environmental Health Hazard Assessment (OEHHA) (Klasing and Brodberg 2008).

** From Mearns et al. 1991. U.S. FDA action limits and all international standards (IS) are for shellfish, but are often applied to fish.

The frequent occurrence of metals and chlorinated hydrocarbons in SBOO fish tissues may be due to multiple factors. Mearns et al. (1991) described the distribution of several contaminants, including arsenic, mercury, DDT, and PCBs as being ubiquitous in the SCB. In fact, many metals occur naturally in the environment, although little information is available on background levels in fish tissues. Brown et al. (1986) determined that no areas of the SCB are sufficiently free of chemical contaminants to be considered reference sites. This has been supported by more recent work regarding PCBs and DDTs (e.g., Allen et al. 1998, 2002). The lack of contaminant-free reference areas in the SCB clearly pertains to the South Bay outfall region, as demonstrated by the presence of many contaminants in fish tissues prior to wastewater discharge (see City of San Diego 2000b).

Other factors that affect the accumulation and distribution of contaminants include the physiology and life history of different fish species (see Groce 2002 and references therein). Exposure to contaminants can vary greatly between different species and among individuals of the same species depending on migration habits (Otway 1991). Fishes may be exposed to contaminants in an area that is highly contaminated and then move into an area that is not. This is of particular concern for fishes collected in the vicinity of the SBOO, as there are many point and non-point sources that may contribute to contamination in the region (see Chapters 2–4); some monitoring stations are located near the Tijuana River, San Diego Bay, and dredged materials disposal sites, and input from these sources may affect fish in surrounding areas.

Overall, there was no evidence that fishes collected in 2009 were contaminated by the discharge of wastewater from the SBOO. Although several individual tissue samples contained concentrations of some metals that exceeded pre-discharge maximums, concentrations of most contaminants were not substantially different from pre-discharge levels (see City of San Diego 2000b). In addition, the few tissue samples that did exceed pre-discharge values were widely distributed among the sampled stations and showed no patterns that could be attributed to wastewater discharge. Finally, there was no other indication of poor fish health in the region, such as the presence of fin rot, other indicators of disease, or any physical anomalies (see Chapter 6).

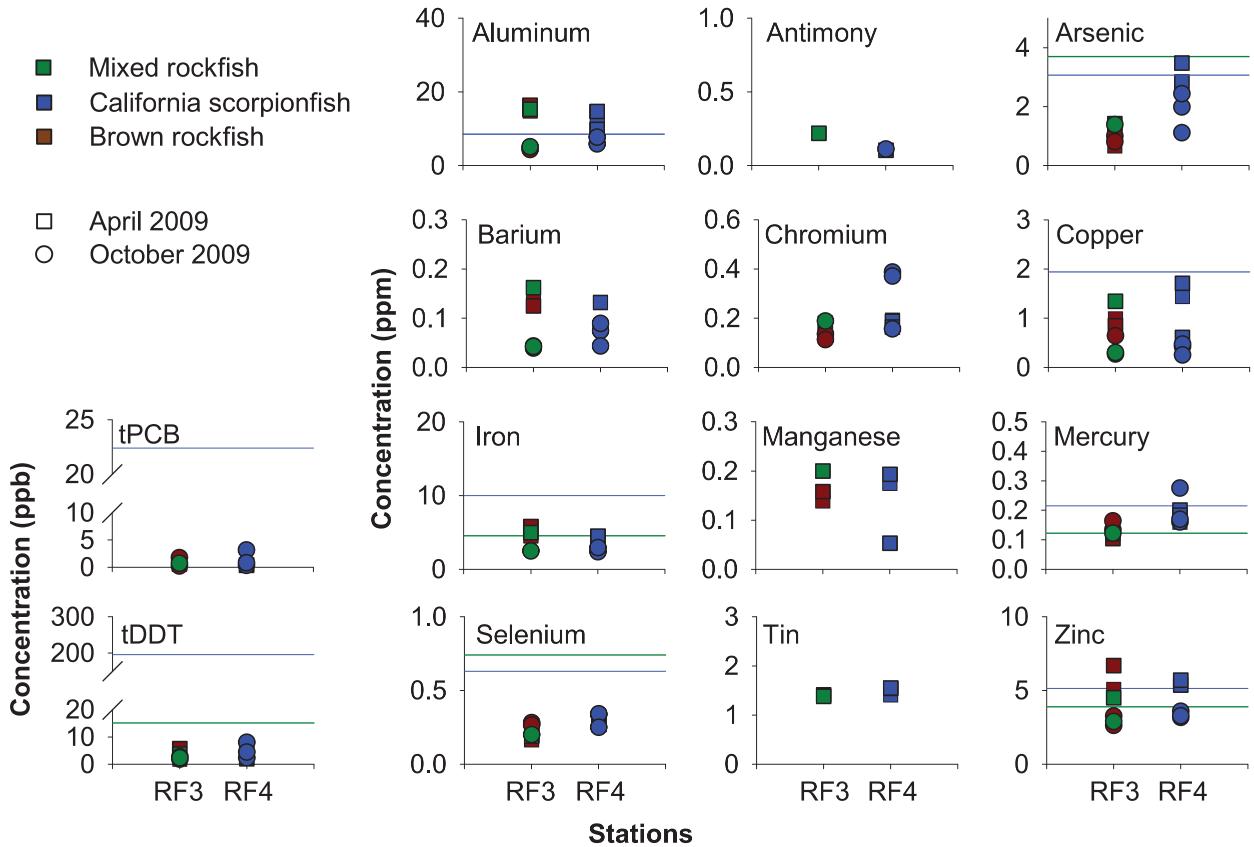


Figure 7.4
Concentrations of frequently detected metals, total (tDDT), and total (tPCB) in muscle tissues of fishes collected from each SBOO rig fishing station during 2009. Reference lines are maximum values detected during the pre-discharge period (1995–1998) for California scorpionfish and mixed rockfish; brown rockfish were not collected during that period. All missing values = non-detects.

Literature Cited

Allen, M.J., S.L. Moore, K.C. Schiff, D. Diener, S.B. Weisburg, J.K. Stull, A. Groce, E. Zeng, J. Mubarak, C.L. Tang, R. Gartman, and C.I. Haydock. (1998). Assessment of demersal fish and megabenthic invertebrate assemblages on the mainland shelf of Southern California in 1994. Southern California Coastal Water Research Project, Westminster, CA.

Allen, M.J., A.K. Groce, D. Diener, J. Brown, S.A. Steinert, G. Deets, J.A. Noblet, S.L. Moore, D. Diehl, E.T. Jarvis, V. Raco-Rands, C. Thomas, Y. Ralph, R. Gartman, D. Cadien, S.B. Weisberg, and T. Mikel. (2002). Southern California Bight 1998 Regional Monitoring Program: V. Demersal Fishes and Megabenthic Invertebrates. Southern California Coastal Water Research Project, Westminster, CA.

Brown, D.A., R.W. Gossett, G.P. Hershelman, C.G. Word, A.M. Westcott, and J.N. Cross. (1986). Municipal wastewater contamination in the Southern California Bight: Part I — Metal and organic contaminants in sediments and organisms. Marine Environmental Research, 18: 291–310.

City of San Diego. (1996). Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 1995. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1997). Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 1996. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1998). Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (1999). Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 1998. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000a). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 1999. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000b). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 1999. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000c). International Wastewater Treatment Plant Final Baseline Ocean Monitoring Report for the South Bay Ocean Outfall (1995–1998). City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2001). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2000. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2004). Quality Assurance Manual, 2003. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). 2009 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Groce, A.K. (2002). Influence of life history and lipids on the bioaccumulation of organochlorines in demersal fishes. Master's thesis. San Diego State University. San Diego, CA.

Hartmann, A.R. (1987). Movement of scorpionfishes (Scorpaenidae: *Sebastes* and *Scorpaena*) in the Southern California Bight. California Fish and Game, 73: 68–79.

Klasing, S. and R. Brodberg (2008). Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment, Sacramento, CA.

Lauenstein, G.G. and A.Y. Cantillo, eds. (1993). Sampling and Analytical Methods of the NOAA National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984–1992: Vol. I–IV. Technical Memorandum NOS ORCA 71. NOAA/NOS/ORCA, Silver Spring, MD.

Love, M.S., B. Axell, P. Morris, R. Collins, and A. Brooks. (1987). Life history and fishery of the California scorpionfish, *Scorpaena guttata*, within the Southern California Bight. Fisheries Bulletin, 85: 99–116.

Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. (1991). Contaminant Trends in the Southern California Bight: Inventory and Assessment. NOAA Technical Memorandum NOS ORCA 62. Seattle, WA.

Otway, N. (1991). Bioaccumulation studies on fish: choice of species, sampling designs, problems and implications for environmental management. In: A.G. Miskiewicz (ed.). Proceedings of a Bioaccumulation Workshop: Assessment of the Distribution, Impacts, and Bioaccumulation of Contaminants in Aquatic Environments. Australian Marine Science Association, Inc./Water Board.

Rand, G.M., ed. (1995). Fundamentals of Aquatic Toxicology: Effects, Environmental Fate, and Risk Assessment. 2nd ed. Taylor and Francis, Washington, D.C.

Schiff, K. and M.J. Allen. (1997). Bioaccumulation of chlorinated hydrocarbons in livers of flatfishes from the Southern California Bight. In: S.B. Weisberg, C. Francisco, and D. Hallock (eds.). Southern California Coastal Water Research Project Annual Report 1995–1996. Southern California Coastal Water Research Project, Westminster, CA.

[U.S. EPA] United States Environmental Protection Agency. (2000). Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment. Status and Needs. EPA-823-R-00-001. U.S. Environmental Protection Agency.

Chapter 8
San Diego Regional Survey
Sediment Conditions

Chapter 8. San Diego Regional Survey Sediment Conditions

INTRODUCTION

The City of San Diego has conducted regional benthic monitoring surveys off the coast of San Diego since 1994 (see Chapter 1). The main objectives of these surveys are: (1) to describe benthic conditions of the large and diverse coastal region off San Diego; (2) to characterize the ecological health of the marine benthos in the area; (3) to gain a better understanding of regional conditions in order to distinguish between areas impacted by anthropogenic versus natural events.

These regional surveys are comprised of an array of stations that are randomly selected for each year using the U.S. Environmental Protection Agency's (EPA) probability-based EMAP sampling design. The 1994, 1998, 2003, and 2008 surveys off San Diego were conducted as part of larger, multi-agency surveys of the entire Southern California Bight (SCB), including the 1994 Southern California Bight Pilot Project (SCBPP), and the 1998, 2003 and 2008 SCB Regional Monitoring Programs (i.e., Bight'98, Bight'03, and Bight'08 respectively). Sediment chemistry results for the 1994–2003 bight-wide surveys are available in Schiff and Gossett (1998), Noblet et al. (2003), and Schiff et al. (2006), while data for the Bight'08 project are not yet available. The same randomized sampling design was used to select 40 new stations per year along the continental shelf (i.e., depths < 200 m) for each of the other surveys restricted to the San Diego region in 1995–1997 and 1999–2002. Beginning in 2005, however, an agreement was reached between the City, the San Diego Regional Water Quality Control Board, and the EPA to revisit the same sites that were successfully sampled 10 years earlier in order to facilitate comparisons of long-term changes in benthic conditions for the region. Thus, 36 sites were successfully revisited in 2005, 34 sites in 2006, and 39 sites in 2007. In 2009, the 34 stations originally sampled in 1999 were revisited. In addition, six new sites were selected to bring the sample size back up to 40 stations and to expand the survey into deeper continental slope waters between 200−500 m in depth.

This chapter presents analysis and interpretation of sediment particle size and chemistry data collected during the 2009 regional survey of continental shelf and upper slope benthic habitats off San Diego. Included are descriptions of the region's sediment conditions during the year, comparisons of sediment characteristics across the major depth strata defined by the SCB regional programs, and evaluation of long-term changes between the 2009 and 1999 surveys.

Materials and Methods

Field Sampling

The July 2009 regional survey covered an area ranging from off La Jolla in northern San Diego County south to the U.S./Mexico border (Figure 8.1). This survey revisited the same 34 sites that were successfully sampled in 1999 based on the EPA probability-based EMAP sampling design (see City of San Diego 2000). Although 40 sites were initially selected in 1999, sampling was unsuccessful at six sites due to the presence of rocky reefs or substrates. In order to augment the sampling design in 2009, six new stations were added using the same selection method, thus bringing the sample size back up to 40 sites. However, these new sites were targeted for continental slope depths (> 200 m) to extend the monitoring program into deeper waters. Overall, the 2009 survey included stations ranging in depth from 11 to 413 m and spanning four distinct strata as characterized by the SCB Regional Monitoring Programs (see 'Data Analyses' section below).

Each sediment sample was collected from one side of a chain-rigged double Van Veen grab with a 0.1-m^2 surface area; the other grab sample from the

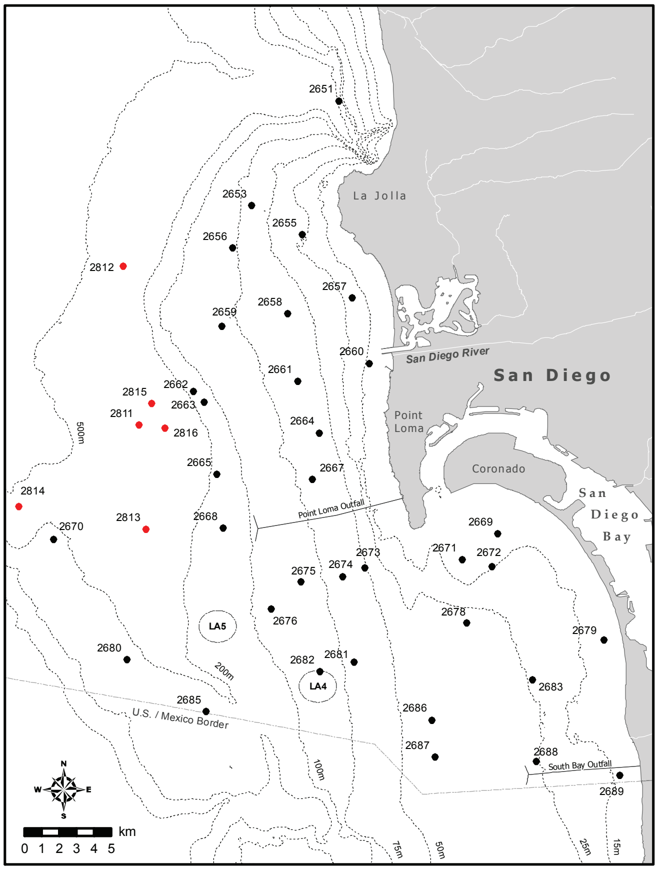


Figure 8.1
Regional benthic survey stations sampled during July 2009 as part of the South Bay Ocean Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

cast was used for macrofaunal community analysis (see Chapter 9) and visual observations of sediment composition. Sub-samples for various analyses were taken from the top 2 cm of the sediment surface and handled according to EPA guidelines (U.S. EPA 1987).

Laboratory Analyses

All sediment chemistry and particle size analyses were performed at the City of San Diego's Wastewater Chemistry Services Laboratory. Particle size analysis was performed using either a Horiba LA-920 laser scattering particle analyzer or a set of six nested sieves. Sieves were used when a sample contained substantial amounts of coarse material (e.g., coarse sand, gravel, shell hash) which would damage the Horiba analyzer and/or where the general distribution of sediment sizes in the sample would be poorly represented by laser analysis. The mesh sizes of the sieves are 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0.063 mm, and thus separate a seventh fraction of all particles finer than 0.063 mm. In the 2009 regional survey, samples from two stations (i.e., 2663 and 2670) were processed by sieve analysis. All other particle size analyses were performed on the Horiba analyzer, which measures particles ranging in size from 0.00049 mm to 2.0 mm (i.e., 11 to -1 phi). Prior to laser analysis, coarser sediments were removed by screening the samples through a 2.0-mm mesh sieve; these data are expressed herein as the "coarse" fraction of the total sample sieved. Results from sieve analysis and output from the Horiba were categorized into sand, silt, and clay fractions as follows: sand was defined as particles ranging between 2.0 and >0.0625 mm in diameter, silt as particles between 0.0625 and >0.0039 mm, and clay as particles between 0.0039 mm and >0.00049 mm. These data were standardized and combined with any sieved coarse fraction (i.e., particles >2.0 mm) to obtain a distribution of coarse, sand, silt and clay fractions totaling 100%. These four size fractions were then used in the calculation of various particle size parameters, which were determined using a normal probability scale (see Folk 1968). These parameters were then summarized and expressed as overall mean particle size (mm), phi size (mean, standard deviation), and the proportion of coarse materials, sand, silt, and clay. Additionally, the proportion of fine particles (percent fines) was calculated as the sum of all silt and clay fractions for each sample.

Each sediment sample was analyzed for total organic carbon (TOC), total nitrogen (TN), total sulfides, trace metals, chlorinated pesticides (e.g., DDT), polychlorinated biphenyl compounds (PCBs), and polycyclic aromatic hydrocarbons (PAHs) on a dry weight basis (see Appendix C.1). TOC and TN were measured as percent weight (% wt) of the sediment sample; sulfides and metals were measured in units of mg/kg and are expressed in this report as parts per million (ppm); pesticides and PCBs were measured in units of ng/kg and expressed as parts per trillion (ppt); PAHs were measured in units of µg/kg and expressed as parts per billion (ppb).

The data for each parameter reported herein were generally limited to values above method detection limits (MDL). However, concentrations below MDLs were included as estimated values if the presence of the specific constituent was verified by mass-spectrometry (i.e., spectral peaks confirmed). A detailed description of the analytical protocols is available in City of San Diego (2010).

Data Analyses

Data summaries for particle size and chemistry parameters included detection rates (i.e., number of reported values/number of samples), annual means of detected values for all stations combined (areal mean), and minimum, median and maximum values during the year. Data were also summarized according to the following four depth strata used in the SCB regional surveys: inner shelf (5–30 m), mid-shelf (30–120 m), outer shelf (120–200 m), and upper slope (200–500 m). Total PAH, total DDT, total HCH, total chlordane, and total PCB were calculated for each sample as the sum of all constituents with reported values; values for each individual constituent are listed in Appendix G.1. Statistical analyses included Spearman Rank correlation of all sediment chemistry parameters with percent fines. This non-parametric analysis accommodates nondetects (i.e., analytes measured below MDLs) without the use of value-substitutions (Helsel 2005). However, depending on the data distribution, the instability in ranked-based analyses may intensify with increased censoring (see Conover 1980). Therefore, a criterion of <50% non-detects was used to screen eligible constituents for this analysis. Results from the correlation analyses were confirmed by graphical analyses.

In addition, data from the 2009 survey were compared to the Effects Range Low (ERL) and Effects Range Median (ERM) sediment quality guidelines of Long et al. (1995) when available to assess contamination levels. The National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA) originally calculated the ERLs and ERMs to provide a means for interpreting monitoring data. The ERLs are considered to represent chemical concentrations below which adverse biological effects are rarely observed. Values above the ERL but below the ERM represent values at which effects occasionally occur. Concentrations above the ERM indicate likely biological effects, although these are not always validated by toxicity testing (Schiff and Gossett 1998). Levels of contamination were further evaluated by comparing 2009 data to those from 1999 for the 34 shelf stations sampled in both surveys.

Results and Discussion

Particle Size Analysis

As in previous surveys (e.g., see City of San Diego 2008), the overall composition of sediments off San Diego in 2009 consisted primarily of sands and fine particles (Table 8.1), although the relative contribution of each size fraction varied by depth and/or by region (e.g., north vs. south; see Figure 8.2). For example, the 11 sites located in shallow water along the inner shelf (i.e., ≤30 m) were composed of about 3% coarse particles, 89% sands, and 8% fines on average, whereas the 15 sites located mid-shelf at depths between 43–95 m and the eight sites located on the outer shelf at 122–177 m had finer sediments (i.e., 41% and 38% fines, respectively). The six sites located along the upper slope at depths >200 m contained the finest sediments, with 69% fines, 31% sands and no coarse fraction.

Correlation analysis confirmed that the proportion of fine sediments increased with depth (Figure 8.3), although some sites along the Coronado Bank (stations 2670, 2680 and 2685) and on the upper slope (station 2814) had higher proportions of sand than sites at similar depths (Appendix G.2). In addition, several sites located south of Point Loma had coarser sediments (<20% fines) than expected for their depth (see Figure 8.2). These results are similar to those from sediments at the fixed-grid monitoring stations surrounding the SBOO (see Chapter 4). Sediments from deeper mid-shelf sites in this South Bay region tend to be coarser and have less fine materials than regional stations at similar depths located off Point Loma and further

Table 8.1

Summary of particle size and sediment chemistry parameters at regional benthic stations during 2009. Data include detected values averaged by depth stratum, as well as the detection rate, minimum (Min), median, maximum (Max), and mean values for the entire survey area. TN = total nitrogen; TOC = total organic carbon; HCH = hexachlorocyclohexane; HCB = hexachlorobenzene; nd = not detected.

	Depth Strata				2009 Survey Area*				
	Inner Shelf	**Mid-shelf**	**Outer Shelf**	**Upper Slope**	**Detection Rate (%)**	**Min**	**Median**	**Max**	**Mean**
Particle Size Fractions (%)									
Coarse	3	1	1	0	**	0	0	26	1
Sand	89	58	61	31	**	17	56	99	63
Fines	8	41	38	69	**	0	43	83	36
Organic Indicators									
Sulfides (ppm)	3.4	1.0	8.3	9.0.	90	nd	1.3	33.4	4.3
TN (% weight)	0.02	0.06	0.08	0.20	100	0.01	0.07	0.30	0.08
TOC (% weight)	0.25	0.81	3.18	2.87	100	0.09	0.81	8.82	1.44
Trace Metals (ppm)									
Aluminum	4990	9241	8531	14167	100	1450	9295	18900	8669
Antimony	0.42	0.55	0.50	—	58	nd	0.42	0.64	0.51
Arsenic	2.32	3.90	3.91	3.93	100	0.74	3.16	9.02	3.47
Barium	27.8	45.3	50.0	82.3	100	3.3	48.7	115.0	47.0
Beryllium	0.07	0.21	0.27	0.40	100	0.02	0.22	0.49	0.21
Cadmium	0.09	0.18	0.22	0.41	78	nd	0.17	0.51	0.22
Chromium	9.3	18.6	20.4	38.0	100	4.8	18.6	68.2	19.3
Copper	3.1	9.8	6.5	17.1	95	nd	8	25.8	8.3
Iron	7005	13983	13685	19033	100	3910	13850	27400	12762
Lead	2.07	5.61	3.92	6.80	100	1.21	4.80	12.10	4.48
Manganese	72.7	98.4	80.5	132.3	100	19.7	98.2	171.0	92.8
Mercury	0.007	0.039	0.026	0.046	80	nd	0.027	0.080	0.032
Nickel	2.8	7.3	7.5	18.0	100	1.0	7.5	22.5	7.7
Selenium	—	0.27	0.33	1.05	35	nd	nd	1.37	0.63
Silver	—	—	—	—	0	nd	nd	nd	—
Thallium	—	—	—	—	0	nd	nd	nd	—
Tin	0.64	1.29	0.85	1.18	98	nd	1.06	1.67	1.00
Zinc	16.5	38.5	32.8	55.6	100	7.1	36.5	81.8	33.9
Pesticides (ppt)									
Total HCH	—	—	—	5050	5	nd	nd	6700	5050
Total Chlordane	—	—	—	1545	5	nd	nd	1760	1545
Total DDT	130	794	540	855	48	nd	nd	1950	664
HCB	177	332	860	335	43	nd	nd	1400	367
Total PCB (ppt)	—	8235	673	880	23	nd	nd	34730	5737
Total PAH (ppb)	—	124.3	—	53.2	15	nd	nd	187.9	88.8

* Minimum, maximum, and median values were calculated based on all samples ($n = 40$), whereas means were calculated on detected values only ($n \leq 40$).

** Particle size parameters calculated for all samples.

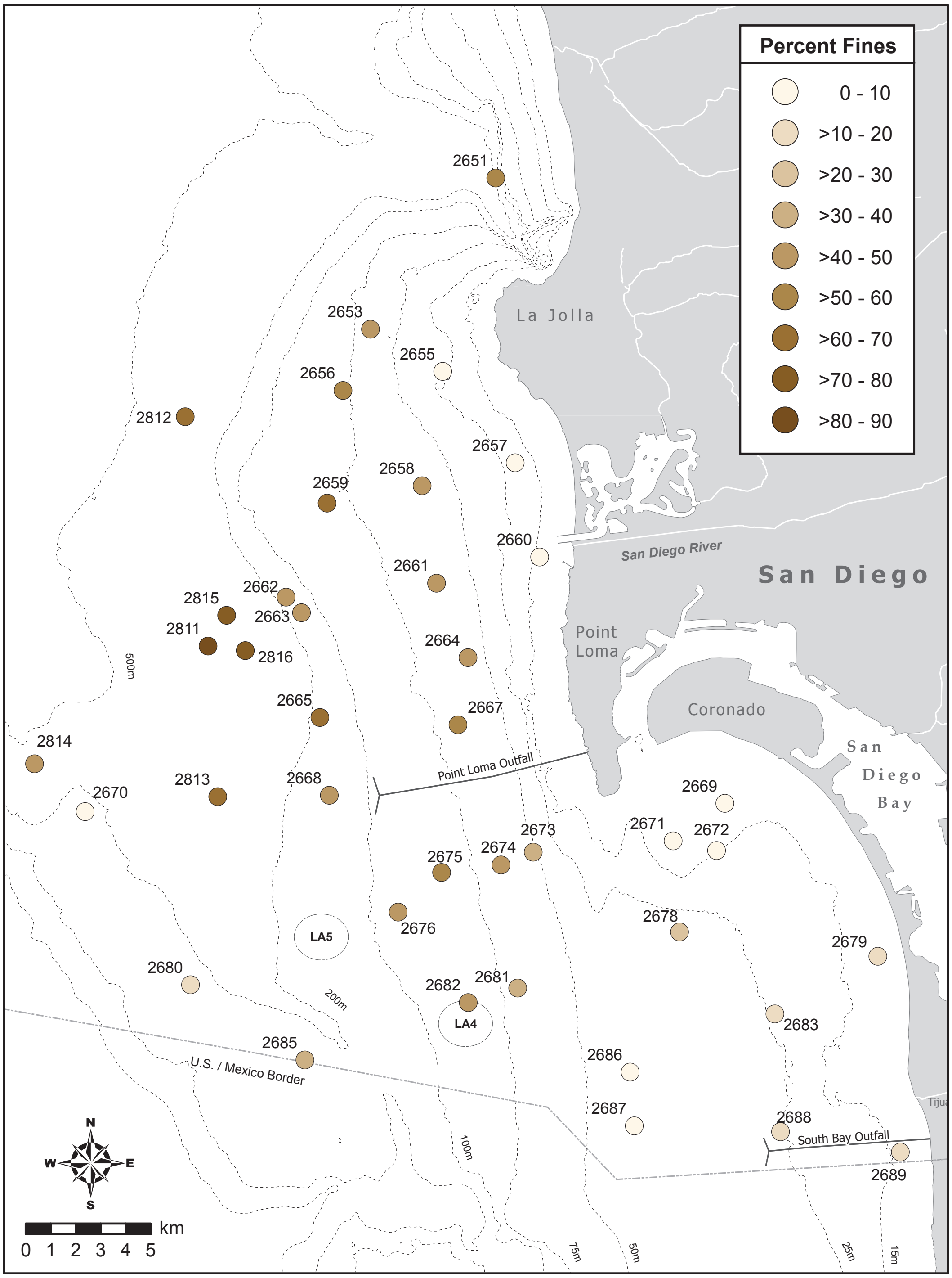


Figure 8.2
Distribution of fine sediments (percent fines) at regional benthic stations sampled during July 2009.

to the north. This may be due, at least in part, to the different geological origins of red relict sands, other coarse sands, shell hash, and detrital sediments in the South Bay region (see Emery 1960).

Sediment particle size composition along the San Diego shelf in 2009 was generally similar to that sampled at the same sites in 1999. Only five of the stations sampled in 2009 (i.e., 2655, 2669, 2672, 2680, 2686) had sediments that differed by 0.1 mm or more in mean particle size when compared to the 1999 samples (see Appendices G.2, G.3). Of these five samples, most exhibited a smaller average particle size in 2009.

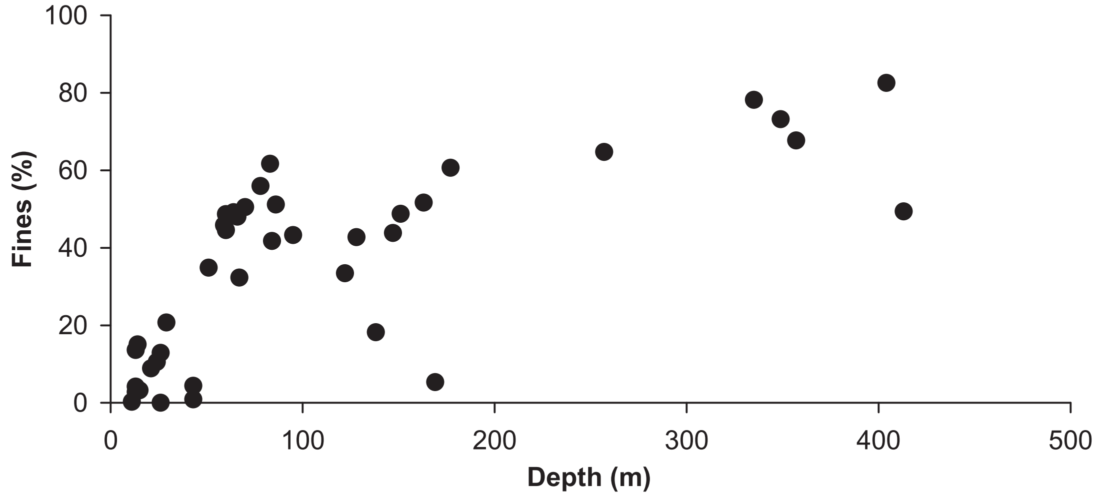


Figure 8.3
Scatterplot of percent fines and depth for regional benthic stations sampled in 2009. Spearman Rank correlation coefficient ($r_s = 0.77$); $p < 0.001$.

Organic Indicators

Sulfides were detected at 90% of the 2009 regional stations, with average concentrations of 3.4 ppm at the inner shelf stations, 1.0 ppm at the mid-shelf stations, 8.3 ppm at the outer shelf stations, and 9.0 ppm at upper slope stations (Table 8.1). The three highest sulfide concentrations were found in sediments from stations located throughout the survey area, including station 2651 (located along the La Jolla Canyon wall at 163 m), station 2665 (located north and offshore of the PLOO at 177 m), and station 2678 (located between the mouth of San Diego Bay and the SBOO at 29 m) (Appendix G.4). Region-wide sulfide concentrations from this study were similar to those reported for the stations within the SBOO monitoring area (Chapter 4) and well within the range of values reported for 1999 (Figure 8.4, Appendix G.5).

Concentrations of TN and TOC co-varied with the proportion of fine sediments in each sample (Table 8.2), and because of this relationship, values for both indicators tended to increase across the continental shelf. For example, TN was found to be correlated tightest with percent fines (Figure 8.5A) and ranged from 0.02% wt at the inner shelf stations to 0.20% wt at the upper slope stations on average (Table 8.1). TOC was also tightly correlated to percent fines, and ranged from 0.25% wt at the inner shelf stations to 3.18% wt at the outer shelf stations on average. TOC concentrations were higher at the outer shelf stations than along the upper slope because sediment samples from two sites along the Coronado Bank (i.e., stations 2680 and 2685) contained the highest TOC levels in the region. The TOC concentrations measured in sediments at these two stations (8.820% and 8.030%, respectively, Appendix G.4) caused the overall TOC range for 2009 to be substantially higher than in 1999, when TOC values ranged from 0.015% to 1.190% (Figure 8.4, Appendix G.5). In contrast, TN did not differ substantially between 1999 and 2009 on a region-wide basis (i.e., values ranged between 0.010–0.125% in 1999, vs. 0.014–0.134% in 2009) (Figure 8.4, Appendix G.4, G.5). Both parameters were generally similar in sediments sampled as part of the regional survey to those sampled within the regular SBOO monitoring area (see Chapter 4).

Trace Metals

Aluminum, arsenic, barium, beryllium, chromium, iron, lead, manganese, nickel and zinc were detected in all sediment samples collected during the 2009 regional survey (Table 8.1). Antimony, cadmium, copper, mercury, selenium and tin were detected less frequently at rates of 35–98%, while

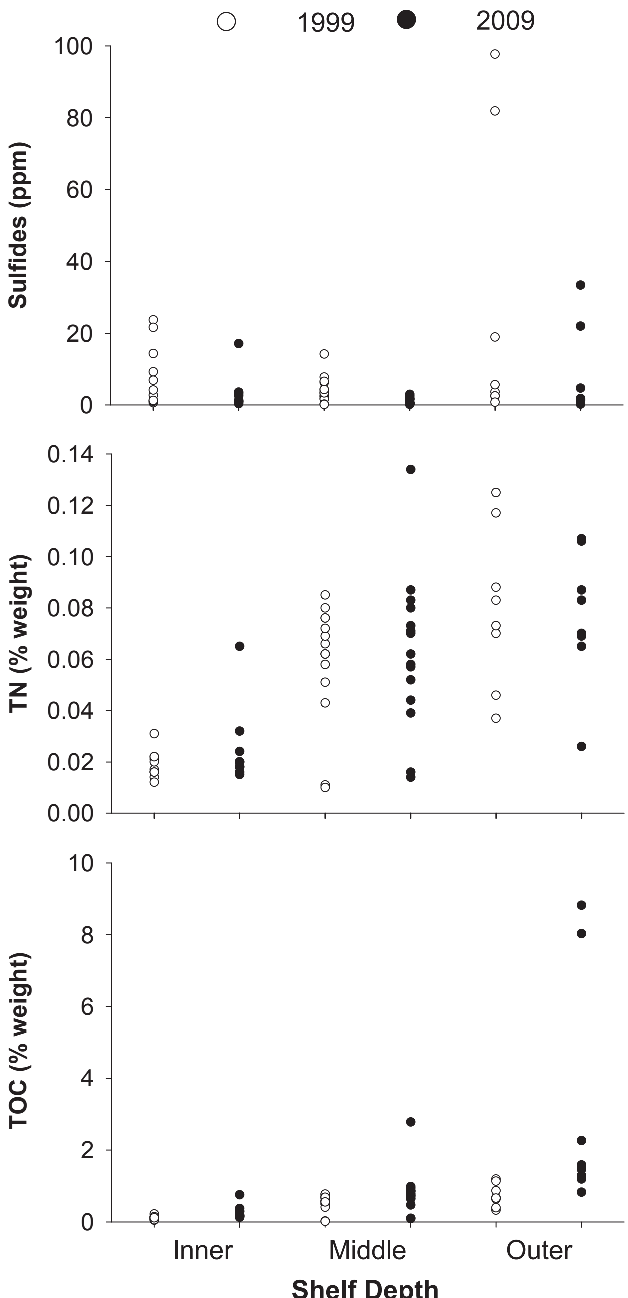


Figure 8.4
Comparison of organic indicator concentrations by shelf depth stratum at regional benthic stations in 1999 vs. 2009. TN = total nitrogen; TOC = total organic carbon; n = 11 (inner), n = 15 (middle), n = 8 (outer); missing values = non-detects.

silver and thallium were not detected at all. As with many of the metals detected within the SBOO monitoring area (see Chapter 4), concentrations of several metals, including aluminum, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, and zinc increased with percent fines (Table 8.2). This relationship was strongest for aluminum (see Figure 8.5B). For these metals, the highest concentrations tended to occur at the deeper sites that had the largest proportion of fine particles (see above). Moreover, the highest values for 15 of the 16 metals detected during the 2009 survey occurred at stations located along the upper slope where the highest levels of percent fines occurred.

Concentrations of some metals also appeared to be associated with the active LA-5 and defunct LA-4 dredge spoils disposal sites. Stations 2674, 2675 and 2676 located between LA-5 and San Diego Bay, and stations 2681 and 2682 located nearest LA-4, had sediments with some of the highest concentrations of several metals, including antimony, copper, lead, mercury, tin and zinc (Appendix G.4). However, sediments at these sites had only moderate proportions of fine particles (i.e., 32–51%) (Appendix G.3). Although some of these stations are located over a kilometer away from the designated disposal sites, the presence of “short dumps” in the region is well documented. For example, mounds of dredged sediments from San Diego Bay have been identified inshore of LA-5, and are therefore considered to be sources of contaminants to the region (Gardner et al. 1998; Parnell et al. 2008). Less is known about the defunct LA-4 dump site as a potential source of contaminated sediments to the survey area. Despite these relatively high values in 2009, only two metals exceeded environmental threshold values. The ERL for arsenic was exceeded at stations 2655 and 2670, while the ERL for nickel was exceeded at stations 2811 and 2816. No samples collected during 2009 had metal concentrations that exceeded ERM thresholds. In addition, most sediment samples collected during 2009 had levels of metals similar to, or lower than, values detected in 1999 (Figure 8.6, Appendix G.5). Exceptions included arsenic, beryllium, chromium, lead, mercury, tin and zinc, each of which were detected above 1999 values (or MDLs) at one or more stations.

Pesticides

Pesticides were detected in less than half of the regional sediment samples collected during 2009 (Table 8.1). Total DDT (primarily p,p-DDE) was

Table 8.2

Results of Spearman Rank correlation analyses of percent fine material with sediment chemistry parameters from regional benthic samples collected in 2009. Shown are analytes which had correlation coefficients (r_s) ≥ 0.60. For all analyses, $p < 0.001$. The strongest correlations with organic indicators and trace metals are illustrated graphically in Figure 8.5 below.

	Analyte	r_s
Organic Indicators (% weight)	Total Nitrogen	0.88
	Total Organic Carbon	0.72
Trace Metals (ppm)	Aluminum	0.92
	Barium	0.80
	Beryllium	0.81
	Cadmium	0.80
	Chromium	0.80
	Copper	0.87
	Iron	0.75
	Lead	0.85
	Manganese	0.91
	Mercury	0.85
	Nickel	0.89
	Tin	0.68
	Zinc	0.86

the most prevalent pesticide, occurring in sediments from 48% of the stations at concentrations averaging about 130 ppt along the inner shelf, 794 ppt along the mid-shelf, 540 ppt along the outer shelf, and 855 ppt along the upper slope. While the upper slope stations had the highest average DDT values, the highest individual concentrations (i.e., >1000 ppt) occurred at mid-shelf stations 2674, 2675, 2681 and 2682 (Appendix G.4). Of these, only a single sample from station 2682 exceeded the ERL for DDT. However, all values reported for the 2009 survey were quite low compared to values reported at some of the regular fixed grid SBOO stations where DDT levels as high as 9400 ppt were detected. These values seemed to be associated with anomalously high levels of percent fines (see Chapter 4). In comparison to the 1999 regional survey, detection rates for DDT were much higher in 2009, but at concentrations within the range of the values reported previously (Figure 8.7, Appendix G.5). The increase in DDT detection rate in 2009 is likely due to the inclusion of estimated values in the analyses (see Methods), a practice that did not begin until 2003.

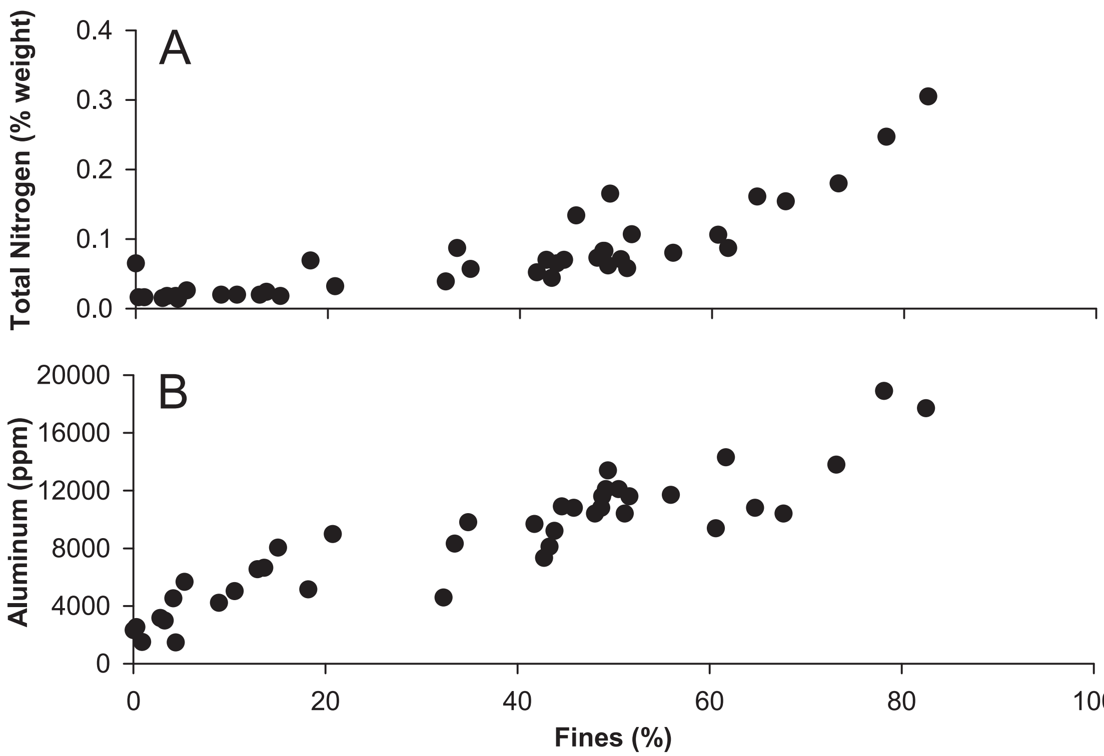


Figure 8.5

Scatterplot of percent fines and concentration of total nitrogen (A) and aluminum (B) in regional sediments in 2009.

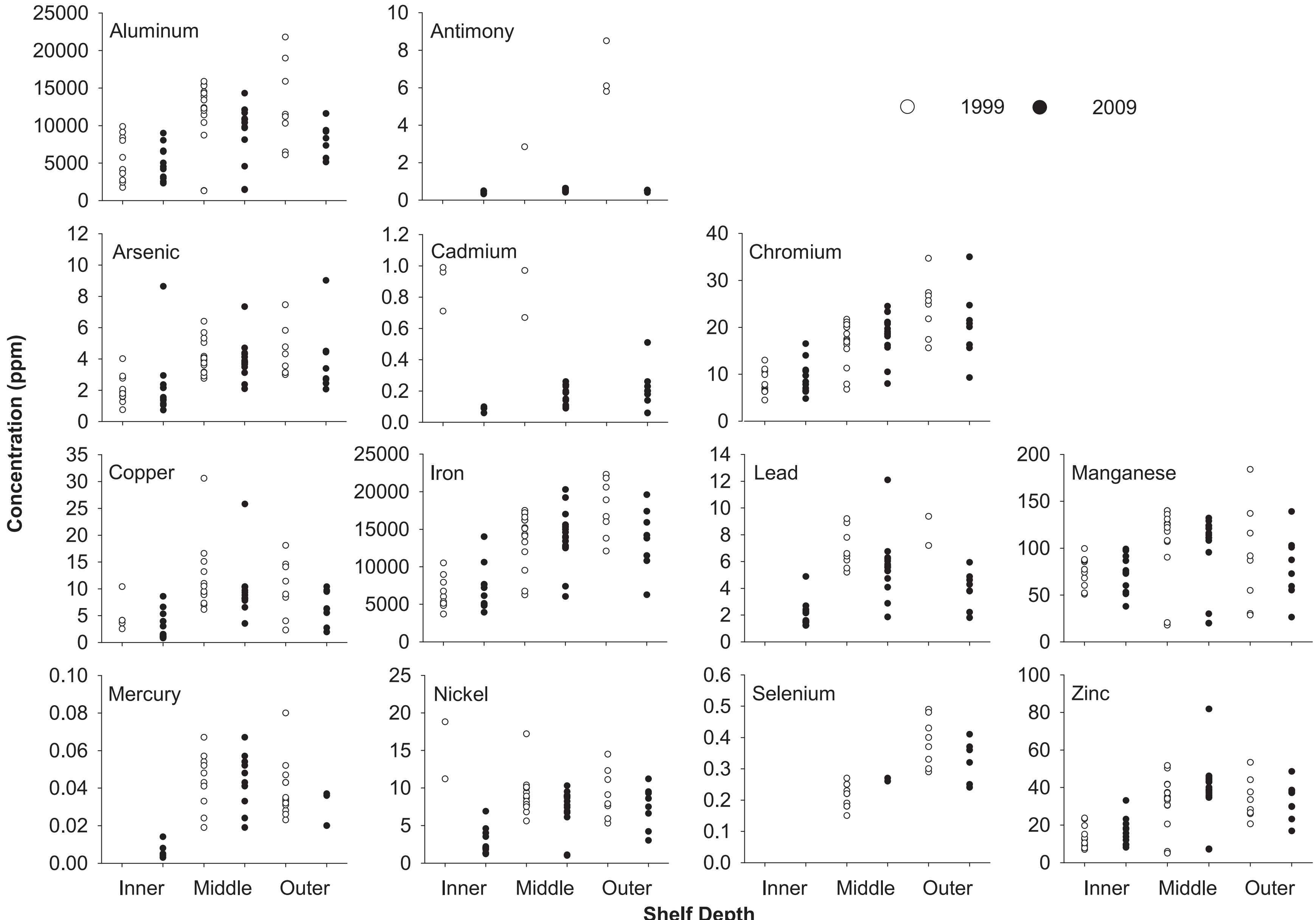


Figure 8.6

Comparison of trace metal concentrations by shelf depth stratum at regional benthic stations in 1999 vs. 2009. Barium was not analyzed in 1999 and is not shown. Four metals (i.e., beryllium, silver, thallium, tin) were not detected in 1999 and are not shown; *n*=11 (inner), *n*=15 (middle), *n*=8 (outer); missing values=non-detects.

Another pesticide, hexachlorobenzene (HCB), was detected almost as frequently as DDT, occurring in sediments from 43% of the stations sampled during the 2009 regional survey. This pesticide occurred throughout the San Diego region, with the highest concentrations occurring at station 2668 (1400 ppt) on the outer shelf and station 2676 (780 ppt) on the mid-shelf. All other samples had HCB concentrations <460 ppt. Concentrations of HCB detected in sediments from the regular SBOO stations were lower overall than those found during the regional survey (see Chapter 4), while analyses were not performed for HCB in 1999. Finally, the pesticides HCH and chlordane were also detected, but at only two sites located at slope depths (i.e., stations 2812 and 2814) that were not sampled in 1999. These two pesticides were not detected in samples collected as part of the SBOO fixed grid survey in 2009.

PCBs and PAHs

PCBs were detected in 23% of the 2009 regional survey sediment samples, most of which came from stations located at mid-shelf depths (Table 8.1, Appendix G.4). The highest total PCB concentration of 34,730 ppt was found in sediments from station 2682 located near the boundary of the inactive LA-4 disposal site. Three additional sites located near LA-4 or between the active LA-5 disposal site and San Diego Bay (i.e., stations 2675, 2676 and 2681) had total PCBs between 2332 and 5867 ppt. In contrast, all other sediment samples had PCB concentrations <2000 ppt. Although the LA-5 site and associated short-dumps are presumed sources of PCB contamination to the region (Parnell et al. 2008), far less is known about the persistence of contaminants in sediments associated with the LA-4 area. Concentrations of PCBs in sediments from regular SBOO monitoring stations were lower overall than those found during the regional survey (see Chapter 4), and no PCBs were detected in sediments during the 1999 regional survey. This lack of PCBs in 1999 may be due in part to the higher MDLs in use at that time.

PAHs were detected in only 15% of the regional stations in 2009, including three sites on the mid-shelf (stations 2675, 2676 and 2682) and three sites along the upper slope (stations 2811, 2815 and 2816) (Table 8.1, Appendix G.4). Sediments from station 2676 located within 1 km of LA-4, and station 2682 located inshore of LA-5, had the highest total PAH levels (165 and 188 ppb, respectively). For these two samples, several constituents comprised total PAH, including benzo[A]anthracene, benzo[A]pyrene, 3,4-benzo[B]fluoranthene, anthracene, chrysene, fluoranthene, and pyrene. In contrast, the other four sites had sediments with PAH concentrations <65 ppb; this consisted primarily of chrysene which may have been due to sample contamination during chemical analysis (see Appendix G.1). The low incidence of PAHs detected in sediments sampled during the 2009 regional survey was consistent with findings from the regular fixed

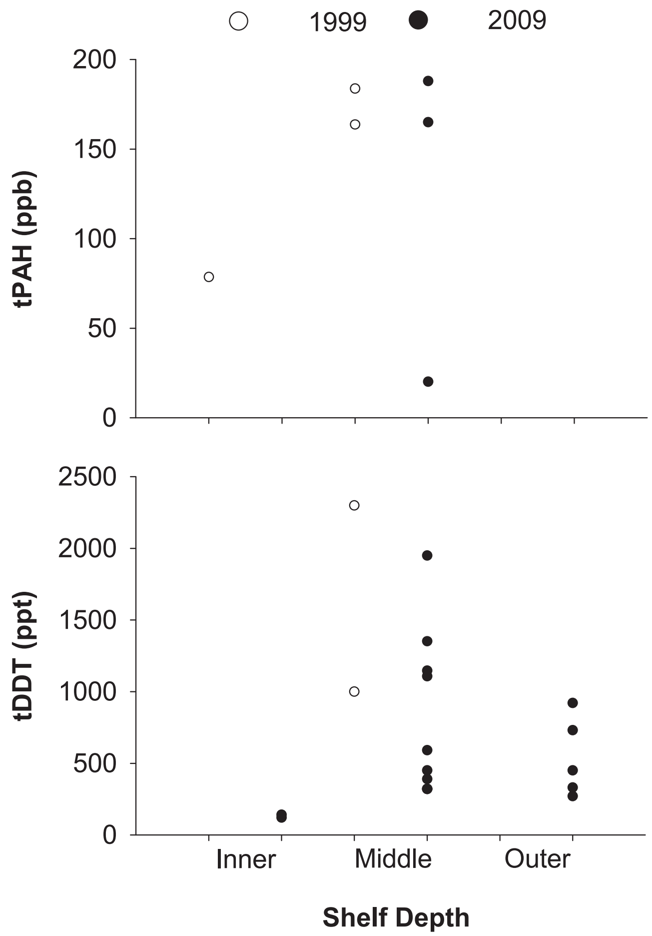


Figure 8.7
Comparison of total PAH (tPAH) and total DDT (tDDT) concentrations by shelf depth stratum at regional benthic stations in 1999 vs. 2009. *n*=11 (inner), *n*=15 (middle), *n*=8 (outer); missing values=non-detects.

grid SBOO monitoring where no PAHs were detected. However, PAHs that were detected in sediments during 2009 were generally similar to concentrations found during the 1999 regional survey (Figure 8.7, Appendix G.5).

Summary and Conclusions

Sediment particle size distribution at the regional benthic stations sampled in 2009 was similar to that seen in previous years. For example, substantial changes in average particle size between 1999 and 2009 were observed for only five sites. As in the past, there was a trend towards higher sand content in nearshore areas compared to finer sands and silt at deeper offshore sites, especially along the upper slope. Exceptions to this general pattern occurred along the Coronado Bank, a southern rocky ridge located southwest of Point Loma at a depth of 150–170 m. Sediment composition at stations from this area tended to be coarser than regional mid-shelf stations located off of Point Loma and further to the north.

As with the particle size distribution, regional patterns of sediment contamination in 2009 were consistent with patterns seen in previous years. Total nitrogen, TOC, and many trace metals generally followed the expected pattern of increasing concentrations with decreasing particle size. As the percent fine fraction of the sediments in this region also increased with depth, many contaminants were detected at higher concentrations in deeper strata compared to the shallow and mid-shelf. For example, the highest concentrations of most contaminants occurred in the sediments of the upper slope, which consisted primarily of very fine particles. High levels of various contaminants also occurred in sediments from stations located near the defunct LA-4 disposal sites, and/or between the active LA-5 disposal site and San Diego Bay. Although these disposal sites were intended to contain contaminated dredged material in deep water, "short dumps" have been recorded inshore of LA-5, as far as 2.5 kilometers from the designated site (Gardner et al. 1998). Increased sediment movement in the inshore area of the mid-shelf could result in the re-suspension and transport of contaminated sediments even further from the intended disposal sites (e.g., Parnell et al. 2008). LA-4 has not been studied as a potential source of contamination in the region, and is no longer an active disposal site. However, high concentrations of trace metals, pesticides, PCBs, and PAHs in sediments surrounding this location may be indicative of persistent contamination. Overall, contaminant concentrations were unremarkable when compared to those from other parts of the Southern California Bight (see Noblet et al. 2003, Maruya and Schiff 2009) and the ERL biological threshold values for sediment contamination were only exceeded in five samples (i.e., arsenic at stations 2655 and 2670, nickel at stations 2811 and 2810, DDT at station 2682).

Literature Cited

City of San Diego. (2000). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 1999. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (International Wastewater Treatment Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). 2009 Annual Reports and Summary: Point Loma Wastewater Treatment Plant and Point Loma Ocean Outfall. City of San Diego, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Conover, W.J. (1980). Practical Nonparametric Statistics, 2ed. John Wiley & Sons, Inc., New York, NY.

Emery, K. O. (1960). The Sea Off Southern California. John Wiley, New York, NY.

Folk, R. L. (1968). Petrology of Sedimentary Rocks. Hemphill, Austin, Texas.

Gardner, J.V., P. Dartnell, and M.E. Torresan. (1998). LA-5 Marine Disposal Site and Surrounding Area, San Diego, California: Bathymetry, Backscatter, and Volumes of Disposal Materials. Administrative Report, July 1998. US Geological Survey, Menlo Park, CA.

Helsel, D.R. (2005). Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc., Hoboken, NJ.

Long, E.R., D.L. MacDonald, S.L. Smith, and F.D. Calder. (1995). Incidence of adverse biological effects within ranges of chemical concentration in marine and estuarine sediments. Environmental Management, 19(1): 81–97.

Maruya, K.A. and K. Schiff. (2009). The extent and magnitude of sediment contamination in the Southern California Bight. In: H.J. Lee and W.R. Normark (eds.). Earth Science in the Urban Ocean: The Southern California Continental Borderland: Geological Society of America Special Paper 454. p 399–412.

Noblet, J.A., E.Y. Zeng, R. Baird, R.W. Gossett, R.J. Ozretich, and C.R. Phillips. (2003). Southern California Bight 1998 Regional Monitoring Program: VI. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.

Parnell, P.E., A.K. Groce, T.D. Stebbins, and P.K. Dayton. (2008). Discriminating sources of PCB contamination in fish on the coastal shelf off San Diego, California (USA). Marine Pollution Bulletin, 56: 1992–2002.

Schiff, K.C. and R.W. Gossett. (1998). Southern California Bight 1994 Pilot Project: Volume III. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

Schiff, K., K. Maruya, and K. Christenson. (2006). Southern California Bight 2003 Regional Monitoring Program: II. Sediment Chemistry. Southern California Coastal Water Research Project. Westminster, CA.

[U.S. EPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

Chapter 9
San Diego Regional Survey
Macrobenthic Communities

Chapter 9. San Diego Regional Survey Macrobenthic Communities

INTRODUCTION

Macrobenthic invertebrates are an important component of the marine ecosystem throughout the entire Southern California Bight (SCB). Because of this and their proven ability to serve as reliable indicators of pollution or other stressors, benthic macrofauna have been sampled extensively over the last several decades to assess environmental impacts around SCB wastewater outfalls and other point sources at small spatial scales (e.g., Stull et al. 1986, 1996; Swartz et al. 1986, Ferraro et al. 1994, Zmarzly et al. 1994, Diener and Fuller 1995, Diener et al., 1995, Stull 1995). Although such local assessments are ongoing, larger-scale regional assessments have become an increasingly important tool over the past 15 years for evaluating benthic community condition and overall sediment quality (e.g., Bergen et al. 1998, 2000; Hyland et al. 2003, Ranasinghe et al. 2003, 2007; U.S. EPA 2004).

The City of San Diego has conducted regional benthic monitoring surveys off the coast of San Diego since 1994 (see Chapter 1). The main objectives of these annual surveys are to: (1) describe benthic conditions of the large and diverse coastal region off San Diego; (2) characterize the ecological health of the marine benthos in the area; (3) gain a better understanding of regional variation in order to distinguish between areas impacted by anthropogenic or natural factors. These regional surveys are comprised of an array of stations selected each year using a probability-based, random stratified sampling design (e.g., see Bergen 1996, Stevens 1997, Stevens and Olsen 2004). The 1994, 1998, 2003, and 2008 surveys off San Diego were conducted as part of larger, multi-agency surveys of the entire SCB, which included the 1994 Southern California Bight Pilot Project (SCBPP) and subsequent Bight'98, Bight'03 and Bight'08 regional monitoring programs. Results of the 1994−2003 SCB surveys are available in Bergen et al. (1998, 2001) and Ranasinghe et al. (2003, 2007, 2010), while data for Bight'08 are not yet available. The same general sampling design was used to select 40 new stations per year along the continental shelf (depths <200 m) for each of the other surveys restricted to the San Diego region in 1995–1997 and 1999–2002. Beginning in 2005, however, an agreement was reached between the City, the San Diego Regional Water Quality Control Board, and the U.S. EPA to revisit the same sites sampled 10 years earlier (i.e., 1995–1997 and 1999) in order to facilitate comparisons of long-term changes in benthic conditions. Thus, 34 stations that were successfully sampled in 1999 were revisited in 2009 along with 6 new sites. These latter new stations were targeted for upper slope depths between 200−500 m to expand the survey into deeper waters.

This chapter presents analysis and interpretation of the macrobenthic invertebrate data collected during the 2009 regional "random array" survey of continental shelf and slope benthic habitats off San Diego. Included are descriptions and comparisons of the soft-bottom macrobenthic assemblages and analyses of benthic community structure for the region.

Materials and Methods

Collection and Processing of Samples

The July 2009 regional survey covered an area ranging from off La Jolla in northern San Diego County south to the U.S./Mexico border (Figure 9.1). This survey revisited the same 34 sites that were successfully sampled in 1999 (see City of San Diego 2000). Although 40 sites were initially selected for the 1999 survey, sampling was unsuccessful at 6 sites due to the presence of rocky reefs or substrates. In order to augment the sampling design in 2009, six new stations were added using the same selection method, thus bringing the sample size

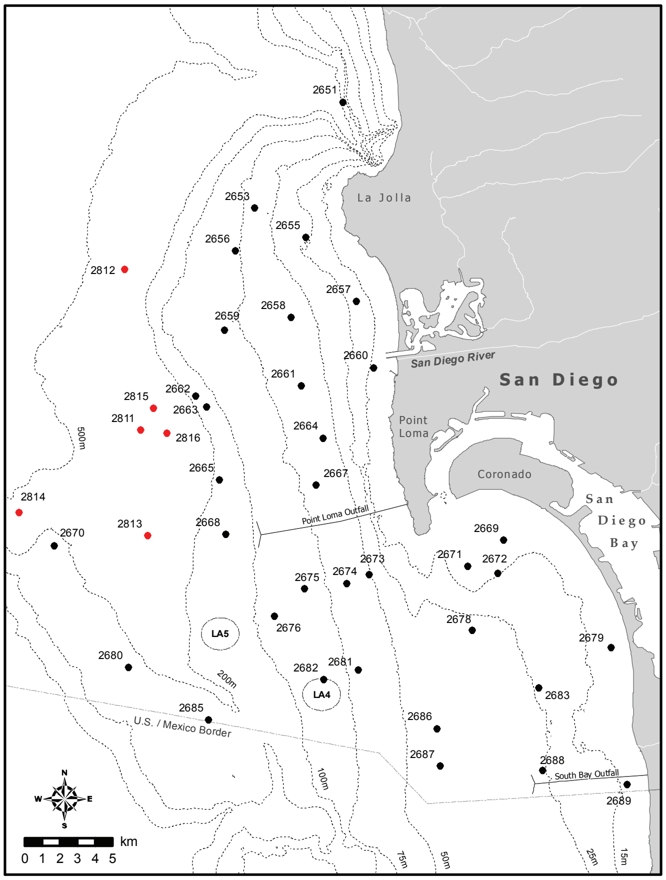


Figure 9.1
Regional benthic survey stations sampled during July 2009 as part of the South Bay Ocean Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

back up to 40 sites. These new sites were targeted for continental slope depths between 200−500 m to extend sampling to deeper habitats. Overall, the 2009 survey included stations ranging in depth from 11 to 413 m and spanning four distinct strata as characterized by the SCB regional monitoring programs (e.g., Ranasinghe et al. 2007).

Samples for benthic community analyses were collected using a double 0.1-m^2 Van Veen grab; one of the two grabs from each cast was used for macrofauna, while the other grab was used for sediment quality analysis (see Chapter 8). Criteria established by the EPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (U.S. EPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen. Organisms retained on the screen were relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the sample debris into major taxonomic groups by a subcontractor, and then identified to species (or the lowest taxon possible) and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (Swartz et al. 1986, Ferraro et al. 1994), and the benthic response index (BRI; Smith et al. 2001). These data are summarized according to depth strata used in the Bight'98, Bight'03, and Bight'08 surveys: inner shelf (5–30 m), mid-shelf (30–120 m), outer shelf (120–200 m), and upper slope (200−500 m). The macrofauna data for 2009 were based on one benthic grab sample per station. While two grabs per station were sampled for macrofauna in the previous 1999 survey, only data from the first grab were reanalyzed here to facilitate comparison to 2009.

Multivariate analyses were performed using PRIMER software to examine spatio-temporal patterns in the overall similarity of benthic assemblages in the region (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (MDS). Macrofaunal abundance data were square-root transformed, and the Bray-Curtis measure of similarity was used as the basis for classification. Similarity profile analysis (SIMPROF) was used to confirm non-random structure of the resulting dendrograms (Clarke et al. 2008), while the 'similarity percentages' routine (SIMPER) was used to identify the species that typified each cluster group. Patterns in the distribution of the resultant assemblages were subsequently compared to several environmental variables by overlaying the physico-chemical data onto the MDS plots based on the macrofauna data (see Field et al. 1982, Clarke and Ainsworth 1993).

Results and Discussion

Community Parameters

Species richness

A total of 632 macrobenthic taxa (mostly species) were identified during the summer 2009 regional survey. Approximately 25% (n=161) of these were rare species or unidentifiable taxa (e.g., juveniles or damaged specimens) that occurred only once. Overall, species richness values (no. species/0.1-m^2 grab) ranged from 20 to 123 species per station at the four depth strata sampled in 2009 (Table 9.1). Such a wide variation in species richness is common for the region and is generally consistent with that observed during previous regional surveys including in 1999 (see Table 9.2). Species richness also varied between the major depth strata during both the 2009 and 1999 surveys (Figure 9.2A). For example, species richness was generally highest along the mid-shelf averaging between 80−93 species/grab during these two years, followed next by averages of 72−75 species/grab along the outer shelf and 60−64 species/grab along the inner shelf. In contrast, considerably fewer species (i.e., mean = 34/grab) occurred at the deeper upper shelf sites that were first sampled in 2009.

Macrofaunal abundance

Macrofaunal abundance at shelf depths ranged from 100 to 630 animals per 0.1-m^2 sample in 2009 compared to 87–1166 individuals per grab in 1999 (Table 9.1, 9.2). The greatest number of animals in 2009 occurred at station 2660 located in shallow waters near the mouth of Mission Bay. Four other sites (i.e., stations 2671, 2678, 2680 and 2686) had abundance values greater than 440 individuals per grab, while the remainder of sites all had less than 400 animals per grab (Table 9.1). Abundance appeared to decrease slightly with depth across the shelf in 2009, averaging about 320 animals/grab along the inner shelf, 298 animals/grab along the mid-shelf, and 236 animals/grab along the outer shelf (see Figure 9.2B). In contrast, abundance values in 1999 were considerably higher at the mid-shelf stations (~415 animals/grab) than along either the inner or outer shelf (i.e., 304−305 animals/grab). Although the cause of this apparent difference is unknown, the pattern of higher abundances along the mid-shelf is more typical for the region. Finally, macrofaunal abundance along the upper slope during the 2009 survey averaged at least two-thirds fewer animals per sample (i.e., 84/0.1 m^2) than abundances at shelf depths during either 1999 or 2009 (Figure 9.2B).

Diversity and evenness

Diversity index (H') values ranged from 1.7 to 4.4 during 2009 (Table 9.1). Although most of the stations had H' values between 3.0−4.0, the five stations with the highest diversity (i.e., H'≥4.0) occurred predominantly along the mid-shelf (Table 9.1). The lowest H' value occurred at station 2671, a shallow-water station located near the mouth of San Diego Bay. Overall, diversity was similar to that observed in 1999 when values ranged from 1.9 to 4.3 (see Table 9.2, Figure 9.2C). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed, and that an assemblage is not dominated by a few highly abundant species. During 2009, J' values averaged between 0.46–0.94 (Table 9.1), with spatial patterns similar to those seen for diversity during both 1999 and 2009 (e.g., Figure 9.2D).

Dominance

Dominance was expressed as the Swartz dominance index, which is calculated as the minimum number of taxa whose combined abundance accounts for 75% of the individuals in a sample. Therefore, lower index values reflect fewer species and indicate higher numerical dominance. Values at the regional shelf stations ranged between 3–55 taxa per station during 2009 and 3–43 taxa per station in 1999, while values at the six deeper upper slope sites in 2009 ranged between 7–28 species (Table 9.1, 9.2). The pattern of dominance across

Table 9.1

Benthic community parameters calculated per 0.1-m^2 grab at regional stations sampled during 2009. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; na = not applicable; n = 1.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
Inner Shelf	2655	26	53	349	3.1	0.77	11	17
	2657	21	73	281	3.7	0.87	26	20
	2660	13	61	630	2.5	0.62	7	4
	2669	11	55	264	3.1	0.78	15	9
	2671	13	45	451	1.7	0.46	3	10
	2672	15	52	156	3.5	0.88	18	18
	2678	29	104	442	3.8	0.81	31	26
	2679	13	45	349	2.6	0.68	7	21
	2683	24	69	272	3.4	0.79	19	18
	2688	26	58	166	3.5	0.85	22	25
	2689	14	40	160	3.2	0.87	14	18
Mid-shelf	2653	59	123	345	4.4	0.92	55	6
	2656	78	53	199	2.8	0.70	15	8
	2658	60	80	291	3.6	0.83	26	7
	2659	83	71	321	3.0	0.71	15	7
	2661	64	84	332	3.6	0.80	24	10
	2664	60	60	209	3.0	0.73	18	13
	2667	70	70	226	3.3	0.79	23	15
	2673	51	107	340	4.0	0.86	39	16
	2674	66	75	382	3.1	0.72	16	14
	2675	86	65	254	2.9	0.68	16	3
	2676	95	107	344	4.1	0.87	40	8
	2681	67	91	255	4.0	0.89	41	13
	2682	84	61	225	3.3	0.80	21	4
	2686	43	88	462	3.4	0.75	18	10
	2687	43	66	279	3.5	0.84	21	7
Outer Shelf	2651	163	82	316	3.7	0.85	27	20
	2662	147	71	237	3.8	0.90	29	16
	2663	128	87	247	3.8	0.86	37	13
	2665	177	42	100	3.5	0.94	21	23
	2668	151	62	137	3.8	0.91	29	11
	2670	169	54	147	3.2	0.80	19	7
	2680	138	109	447	4.0	0.84	30	6
	2685	122	72	258	3.7	0.86	25	10
Upper Slope	2811	404	20	54	2.3	0.78	7	na
	2812	357	27	87	2.7	0.83	11	na
	2813	257	56	112	3.7	0.92	28	20
	2814	413	29	62	3.1	0.92	14	na
	2815	349	34	106	3.0	0.84	12	na
	2816	335	35	85	3.0	0.86	14	na

Table 9.2

Benthic community parameters calculated per 0.1-m^2 grab at regional stations sampled during 1999. SR = species richness; Abun = abundance; H' = shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; *n* = 1.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
Inner Shelf	2655	26	75	182	3.9	0.89	32	16
	2657	21	106	390	3.8	0.81	34	14
	2660	13	47	152	3.1	0.80	13	9
	2669	11	31	251	2.2	0.63	5	-1
	2671	13	60	637	2.3	0.56	7	9
	2672	15	34	356	1.9	0.53	3	1
	2678	29	107	395	4.1	0.89	37	23
	2679	13	43	211	3.1	0.82	13	17
	2683	24	81	406	3.6	0.81	21	14
	2688	26	85	229	3.9	0.88	35	22
	2689	14	33	141	2.9	0.84	10	14
Mid-shelf	2653	59	189	1166	4.2	0.81	42	3
	2656	78	80	473	3.1	0.72	13	2
	2658	60	88	313	3.5	0.79	23	11
	2659	83	65	294	2.8	0.66	10	-2
	2661	64	58	236	3.2	0.79	16	10
	2664	60	81	330	3.5	0.79	21	13
	2667	70	75	380	3.2	0.73	15	13
	2673	51	134	534	4.3	0.87	43	18
	2674	66	94	402	3.2	0.71	18	13
	2675	86	76	444	3.0	0.68	12	3
	2676	95	130	489	4.2	0.86	38	3
	2681	67	106	326	4.0	0.87	37	6
	2682	84	83	315	3.6	0.81	23	4
	2686	43	72	319	3.2	0.74	16	6
	2687	43	66	200	3.5	0.84	23	8
Outer Shelf	2651	163	60	371	2.4	0.59	6	21
	2662	147	75	421	3.5	0.82	22	10
	2663	128	133	619	4.1	0.83	34	4
	2665	177	41	141	3.0	0.81	13	8
	2668	151	68	278	3.4	0.80	20	8
	2670	169	57	157	3.5	0.86	23	-4
	2680	138	46	87	3.6	0.94	25	4
	2685	122	116	361	4.2	0.88	40	1

depth strata was generally similar between the 2009 and 1999 regional surveys (Figure 9.2E). For example, dominance was notably higher (i.e., lower index values) along the inner shelf (mean = 16–19 taxa) than at either the mid- or outer shelf stations (mean = 23–27 taxa) at these times. Average dominance at the upper slope stations in 2009 was similar to that seen along the inner shelf (i.e., mean = 14 taxa). As expected, dominance values also appeared to track diversity. During 2009 for example (see Table 9.1), the three sites with the lowest dominance (i.e., stations 2653, 2681 and 2676; index values ≥ 40) all had high H' values (i.e., ≥ 4.0), while the few stations with dominance index values < 10 (stations 2660, 2671, 2679 and 2811) had relatively lower H' values of 1.7–2.6.

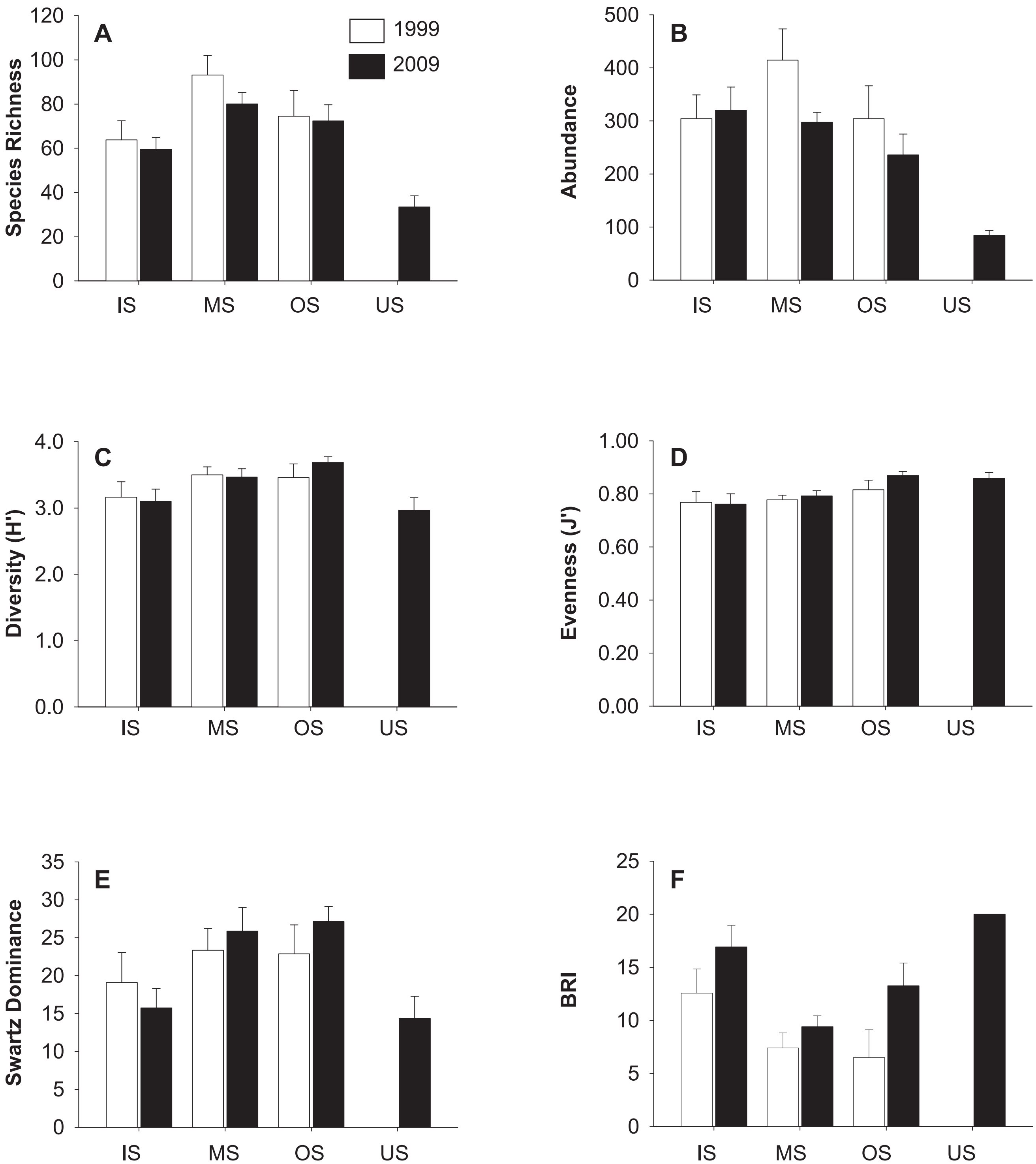


Figure 9.2

Comparison of benthic community structure metrics for the 2009 and 1999 regional surveys off San Diego (see text for details). Data are expressed for each depth stratum as means + one standard error (per 0.1 m^2) except for BRI on the upper slope where $n = 1$. IS = inner shelf (5–30 m; $n = 11$); MS = mid-shelf (30–120 m; $n = 15$); OS = outer shelf (120–200 m; $n = 8$); US = upper slope (200–500 m; $n = 6$ for 2009 only).

Benthic Response Index (BRI)

The benthic response index (BRI) is a useful tool for evaluating environmental conditions in soft-bottom benthic habitats off southern California that was originally calibrated for depths from 5 to 324 m (Smith et al. 2001). Index values below 25 (on a scale of 100) are considered indicative of reference conditions, while those between 25 and 34 represent a minor or marginal deviation that should be confirmed by additional sampling. Higher BRI values > 34 are considered to represent progressive levels of impact, including losses in biodiversity or community function, and ultimately defaunation. BRI values ranged from 3 to 26 at the regional shelf stations in 2009 (Table 9.1). Thus, BRI values throughout the San Diego region were mostly indicative of reference conditions during the year. Only two stations (2688 and 2678) had slightly higher BRI values of 25–26, and these occurred at shallow depths along the inner shelf where the BRI can be less reliable (Ranasinghe et al. 2010). These same two stations also had the highest BRI values in 1999, although no station sampled during that survey had a BRI ≥25 (see Table 9.2). Average BRI values also varied between the major depth strata, although all remained characteristic of reference conditions as discussed above (see Figure 9.2F). For example, during the 1999 and 2009 surveys, respectively, BRI values averaged 13 and 17 along the inner shelf, 7 and 9 at the mid-shelf sites, and 7 and 13 along the outer shelf. Although a BRI of 20 is reported herein for station 2813 located at 257 m on the upper slope, the reliability of this value is questionable as there has been only limited calibration of the index for depths between 200–324 m (Ranasinghe et al. 2010). Additionally, index values were not calculated for the five deeper slope stations since there has been no calibration of the BRI for sites greater than 324 m depth.

Dominant Taxa

Macrofaunal communities in the San Diego region were generally dominated by annelids (i.e., mostly polychaete worms) in 2009 (Table 9.3), although proportions of the various taxa varied between the four depth strata (Figure 9.3). Polychaetes were the most diverse of the major taxa over all strata, accounting for 51% of all species collected. Molluscs and arthropods (mostly crustaceans) were the next two most diverse taxa, accounting for 19% and 18% of species, respectively. Echinoderms comprised 6% of all taxa, while all other phyla combined (e.g., Chordata, Cnidaria, Nematoda, Nemertea, Phoronida, Platyhelminthes, Sipuncula) accounted for the remaining 6%. A few patterns were apparent in the proportions of the major taxa comprising the different assemblages (see Figure 9.3A). For example, the percentage of polychaetes increased across the continental shelf from 47% along the inner shelf, to 52% along the mid-shelf, to 61% along the outer shelf. Echinoderms also increased slightly across these depths, while the proportions of crustaceans, molluscs and the other phyla appeared to decrease. The greatest difference occurred along the upper slope where the percentage of molluscs increased sharply to comprise about 32% of all taxa. Echinoderms also accounted for a larger proportion of species at upper slope sites than on the shelf, while the proportions of polychaetes and crustaceans decreased compared to the outer shelf.

Table 9.3
The percent composition of species and abundance by phyla for regional stations sampled during 2009. Data are expressed as means (range) for all stations combined; $n = 40$.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	51 (31–73)	51 (19–85)
Arthropoda (Crustacea)	18 (0–33)	12 (0–32)
Mollusca	19 (7–41)	21 (3–70)
Echinodermata	6 (0–14)	13 (0–48)
Other Phyla	6 (0–15)	3 (0–22)

Polychaetes were also the most numerous invertebrates overall, accounting for 51% of the total abundance. Molluscs accounted for 21% of the animals, crustaceans 12%, echinoderms 13%, and the remaining

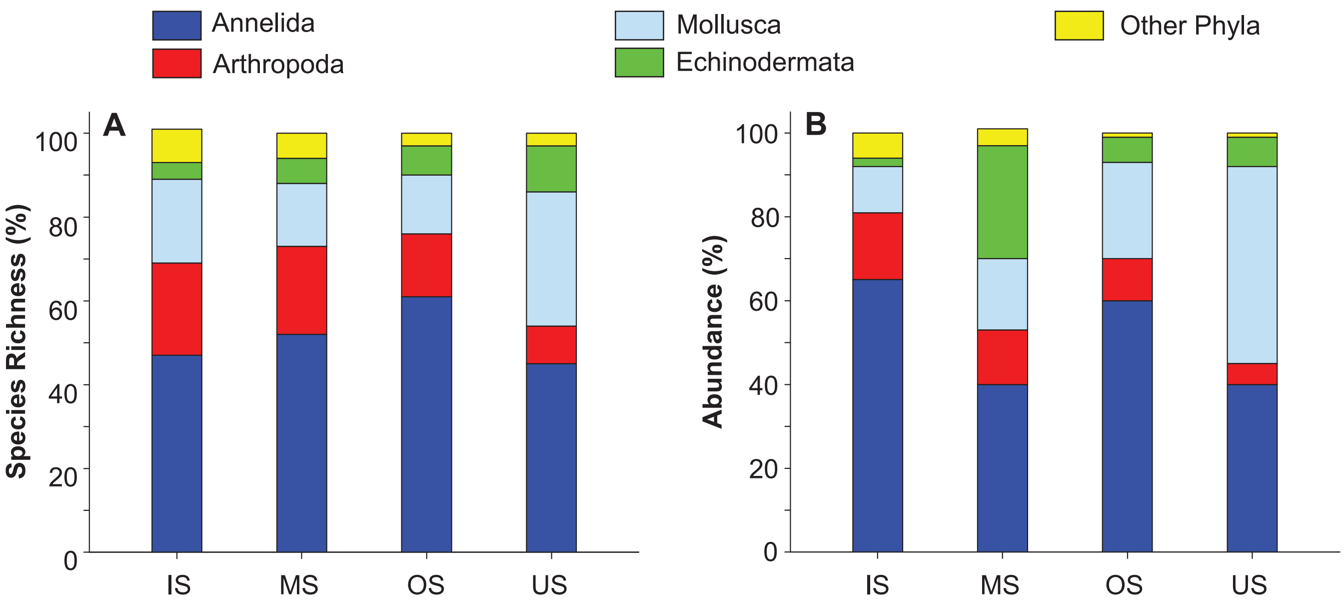


Figure 9.3

Comparison of percent composition of species and abundance by major phyla for each depth stratum sampled at the regional stations during 2009. IS = inner shelf (5–30 m; *n* = 11); MS = mid-shelf (30–120 m; *n* = 15); OS = outer shelf (120–200 m; *n* = 8); US = upper slope (200–500 m; *n* = 6).

phyla 3%. Abundance patterns also varied between strata (see Figure 9.3B). For example, the proportion of polychaetes was lower at the mid-shelf and upper slope stations (i.e., 40% each) than along either the outer or inner shelf (i.e., 60−65%). The lower proportion of polychaetes along the mid-shelf and upper slope corresponded to considerably higher numbers of ophiuroids at mid-shelf depths (i.e., 27%) and molluscs at the deeper slopes sites (i.e., 47%).

As expected, the numerically dominant species characteristic of the benthic assemblages off San Diego also varied between strata (see Table 9.4). For example, the top 10 most abundant species along the inner shelf included eight polychaetes, one cumacean, and one anthozoan. Of these, the oweniid polychaete *Owenia collaris*, and the spionid polychaete *Spiophanes norrisi*, were clearly dominant with averages of about 65 and 21 individuals per 0.1-m^2 grab, respectively. The remaining inner shelf species all averaged < 11 animals/grab. Additionally, *S. norrisi* was the most widely distributed of these species occurring at all 11 of the inner shelf sites. In contrast, *O. collaris* had a more restricted distribution occurring at only six sites. The top 10 dominants along the mid-shelf included four ophiuroid taxa, four polychaetes, and two bivalves. The brittle star *Amphiodia urtica* was by far the most common invertebrate at these depths, averaging about 58 animals per grab and occurring at 87% of the sites. However, it is likely that two of the other "dominant" ophiuroid taxa reported here (i.e., *Amphiodia* sp and Amphiuridae) represent mostly juvenile *A. urtica* that could not be identified to species. Thus, if total *A. urtica* abundance is adjusted to include putative *A. urtica* juveniles, then the estimated density would increase to about 69 brittle stars per grab. The bivalve *Axinopsida serricata* was the next most abundant species at the mid-shelf stations, averaging about 18 animals per grab, while all other species at these depths averaged < 10 animals/grab. The top 10 species along the outer shelf included six polychaetes, three bivalves, and one gastropod. However, densities were relatively low with neither of the two most abundant species on the outer shelf, the bivalves *Tellina carpenteri* and *A. serricata*, exceeding mean densities of 13 animals/grab. The 10 most abundant species at upper slope depths included five bivalves and two scaphopods, as well as three polychaete taxa. The bivalves *Nuculana conceptionis* and *Macoma carlottensis* were the two most abundant species on the upper slope, each averaging about 9 animals/grab.

Table 9.4

The 10 most abundant macroinvertebrates collected at the regional benthic stations sampled during 2009. AS = abundance/survey; PO = percent occurrence; AO = abundance/occurrence. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Strata	Species	Higher Taxa	AS	PO	AO
Inner Shelf	*Owenia collaris*	Annelida: Oweniidae	64.5	55	118.5
	Spiophanes norrisi	Annelida: Spionidae	20.7	100	20.7
	Zaolutus actius	Cnidaria: Anthozoa	10.2	36	27.9
	Monticellina siblina	Annelida: Cirratulidae	8.7	46	19.2
	Mooreonuphis nebulosa	Annelida: Onuphidae	6.9	18	38.4
	Mediomastus sp	Annelida: Capitellidae	6.6	91	7.5
	Polydora cirrosa	Annelida: Spionidae	6.6	27	24.6
	Diastylopsis tenuis	Arthropoda: Cumacea	6.6	55	12.3
	Spiophanes duplex	Annelida: Spionidae	6.6	82	8.1
	Spio maculata	Annelida: Spionidae	5.4	9	60.0
Mid-shelf	*Amphiodia urtica*	Echinodermata: Ophiuroidea	57.9	87	66.9
	Axinopsida serricata	Mollusca: Bivalvia	18.0	87	20.7
	Spiophanes norrisi	Annelida: Spionidae	9.9	20	49.8
	Amphiodia sp	Echinodermata: Ophiuroidea	7.5	80	9.3
	Spiophanes berkeleyorum	Annelida: Spionidae	6.3	80	7.8
	Ennucula tenuis	Mollusca: Bivalvia	5.4	73	7.5
	Euclymeninae sp A	Annelida: Maldanidae	4.5	87	5.1
	Mooreonuphis sp SD1	Annelida: Onuphidae	3.9	13	29.1
	Ophiuroconis bispinosa	Echinodermata: Ophiuroidea	3.6	67	5.4
	Amphiuridae	Echinodermata: Ophiuroidea	3.6	73	4.8
Outer Shelf	*Tellina carpenteri*	Mollusca: Bivalvia	12.9	88	14.7
	Axinopsida serricata	Mollusca: Bivalvia	11.4	75	15.3
	Aphelochaeta glandaria complex	Annelida: Cirratulidae	8.4	62	13.2
	Fauveliopsis sp SD1	Annelida: Fauveliopsidae	8.1	25	32.4
	Terebellides californica	Annelida: Trichobranchidae	8.1	50	15.9
	Micranellum crebricinctum	Mollusca: Gastropoda	6.6	38	17.4
	Monticellina siblina	Annelida: Cirratulidae	6.0	75	8.1
	Mediomastus sp	Annelida: Capitellidae	6.0	88	6.6
	Chaetozone sp	Annelida: Cirratulidae	5.7	38	15.3
	Parvilucina tenuisculpta	Mollusca: Bivalvia	5.4	100	5.4
Upper Slope	*Nuculana conceptionis*	Mollusca: Bivalvia	9.3	83	11.1
	Macoma carlottensis	Mollusca: Bivalvia	8.7	67	13.2
	Maldane sarsi	Annelida: Maldanidae	5.4	67	8.1
	Maldanidae	Annelida: Maldanidae	5.1	67	7.8
	Gadila tolmiei	Mollusca: Scaphopoda	2.4	100	2.4
	Compressidens stearnsii	Mollusca: Scaphopoda	2.4	67	3.9
	Ennucula tenuis	Mollusca: Bivalvia	2.1	83	2.4
	Spiophanes kimballi	Annelida: Spionidae	2.1	67	3.0
	Saxicavella pacifica	Mollusca: Bivalvia	2.1	17	12.0
	Tellina carpenteri	Mollusca: Bivalvia	1.8	33	5.4

Classification of Macrobenthic Assemblages

Classification and ordination analyses were used to discriminate between the major macrobenthic assemblages that occur off San Diego. Two separate analyses were conducted this year, the first which compared the macrofaunal abundance data collected during both 1999 and 2009 at the 34 continental shelf stations (i.e., $n = 68$ station/survey entities). The six deeper slope stations sampled in 2009 were excluded from this analysis. Most stations sampled in 2009 clustered with or closely to their 1999 counterparts (see Appendix H.1), thus suggesting that macrofaunal communities along the San Diego shelf remained generally similar during these two periods. Consequently, a more detailed assessment was performed restricted to just the stations sampled in 2009, including both shelf and slope sites (i.e., $n = 40$ stations). The results of this second analysis are described below.

Seven main habitat-related macrobenthic assemblages were identified in 2009 based on results of the ordination and cluster analyses (Figure 9.4). These assemblages, referred to herein as cluster groups A–G, varied in terms of the specific taxa (mostly species) present and the relative abundance of each taxon, and occurred at sites separated by different depths and/or sediment microhabitats (see Figure 9.5, 9.6). The SIMPROF procedure indicated statistically significant non-random structure among samples ($\pi = 7.92$, $p < 0.001$), and an MDS ordination supported the validity of the cluster groups (Figure 9.4B). SIMPER analysis was used to identify species that were characteristic, though not always the most abundant, of each assemblage. For example, the three most characteristic species identified by SIMPER for cluster groups B–G are indicated in Figure 9.4A; the exception to this is that the three most abundant species are listed for cluster group A, since this group is comprised of a single sample for which the SIMPER routine cannot be performed. A complete list of species comprising each cluster group and their relative abundances can be found in Appendix H.2.

Cluster group A represented a unique assemblage restricted to station 2655 sampled in relatively shallow water (26 m) off the southwest tip of La Jolla, which was associated with very coarse sediments. A total of 53 taxa and 349 individuals occurred in this single 0.1 m^2 grab sample. This inner shelf assemblage was characterized by several species of polychaetes that commonly occur in coarse benthic habitats, including the spionid *Spio maculata*, the lumbrinerid *Lumbrinerides platypygos*, the pisionid *Pisione* sp, and the phyllodocid *Hesionura coineaui difficilis*. Another species common in coarse sediments, the cephalochordate *Branchiostoma californiense*, was present as well. Sediments at this site were comprised almost entirely of sand and shell hash with 0% fines, and with a total organic carbon (TOC) content of 0.8% weight (% wt).

Cluster group B represented an assemblage from six inner shelf stations that ranged in depth from 11 to 14 m. The assemblage at these stations was typical of shallow-water sites in the region, and had an average of 50 taxa and 335 individuals per 0.1 m^2. Characteristic species included the oweniid polychaete *Owenia collaris*, and the spionids *Spiophanes norrisi* and *S. duplex*. Sediment composition at the sites within this group averaged 7% fines and 0.2% wt TOC.

Cluster group C represented an assemblage from six sites located at depths between 21 and 43 m. Species richness for this inner to shallow mid-shelf assemblage averaged 76 taxa, while abundance averaged 317 individuals per 0.1 m^2. Polychaetes were numerically dominant, with the spionids *Spiophanes norrisi* and S. *berkeleyorum*, as well as the maldanid Euclymeninae sp A, representing the three most characteristic species. Sediments at these sites were comprised mostly of coarse particles, including shell hash and red relict sand with an average of only 10% fines, along with an average TOC content of 0.2% wt.

Cluster group D represented the deepest assemblage sampled at five of the six sites located along the upper continental slope at depths between 335 and 413 m.

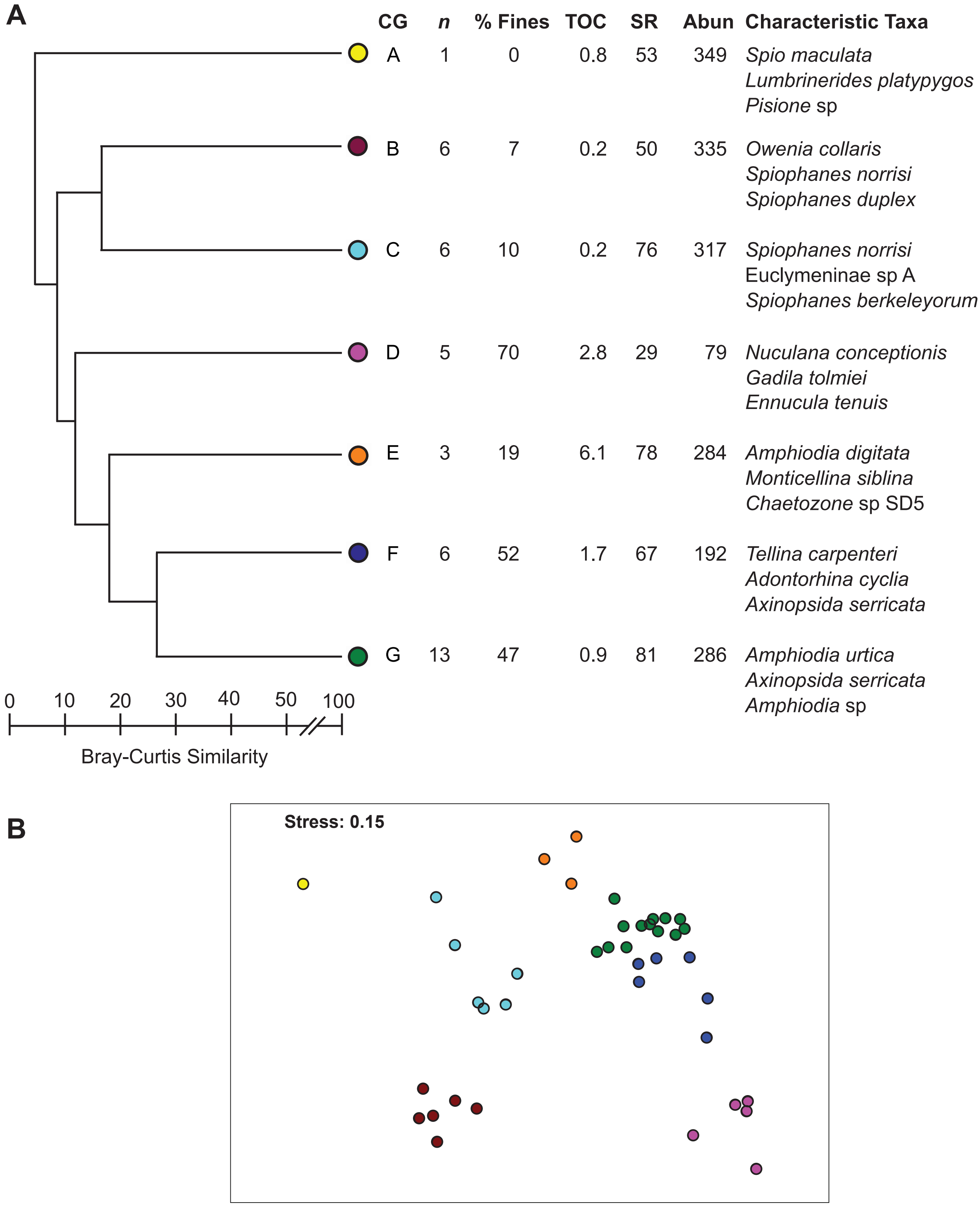


Figure 9.4

(A) Cluster results of the macrofaunal abundance data for the regional benthic stations sampled during summer 2009. Data for percent fines, total organic carbon (TOC), species richness (SR), and infaunal abundance (Abun) are expressed as mean values per 0.1-m^2 grab over all stations in each group. (B) MDS ordination based on square-root transformed macrofaunal abundance data for each station.

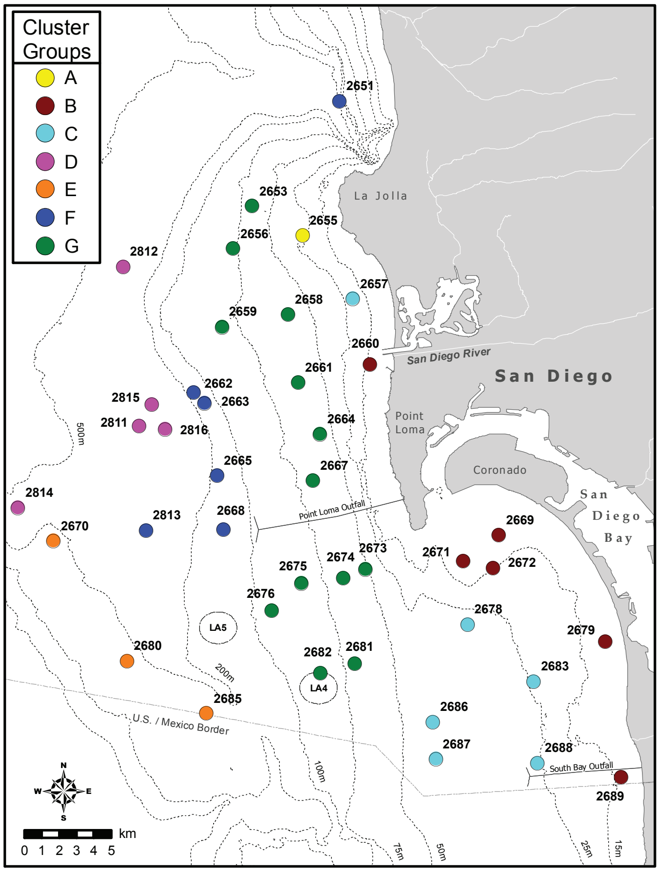


Figure 9.5
Spatial distribution of the 2009 regional macrobenthic assemblages delineated by ordination and classification analyses.

This assemblage averaged 29 taxa and 79 individuals per 0.1 m^2, the lowest values among all cluster groups. Molluscs were numerically dominant at these upper slope sites, with the three most characteristic species being the bivalves *Nuculana conceptionis* and *Ennucula tenuis*, and the scaphopod *Gadila tolmiei*. The sediments characteristic of these deep samples averaged considerably finer particles (i.e., 70% fines) compared to those in the other six groups (i.e., 0–52% fines), and had an average TOC value of 2.8% wt.

Cluster group E represented an assemblage from three stations located on the Coronado Bank at depths of 122–169 m. This outer shelf assemblage averaged 78 taxa and 284 individuals per 0.1 m^2. The characteristic species included the ophiuroid *Amphiodia digitata*, and the cirratulid polychaetes *Monticellina siblina* and *Chaetozone* sp SD5. The sediments characteristic of these samples were relatively coarse containing pea gravel, rock, shell hash and 19% fines. TOC content at these sites averaged of 6.1% wt, which was considerably higher than for any of the other groups.

Cluster group F represented an assemblage present at six sites, including five outer shelf stations at depths of 128–177 m, as well as the shallowest upper slope station at 257 m (i.e., station 2813). This assemblage averaged 67 taxa and 192 individuals per 0.1 m^2. The three most characteristic species were the bivalves *Tellina carpenteri*, *Adontorhina cyclia*, and *Axinopsida serricata*. Sediments at these sites averaged 52% fines and had an average TOC content of 1.7% wt.

Cluster group G represented an assemblage from most of the mid-shelf sites (n=13) that ranged in depth from 51 to 95 m. This group had the highest average species richness (81 species) and averaged 286 individuals per 0.1 m^2. Overall, this assemblage is typical of the ophiuroid dominated community that occurs along much of the mainland shelf off southern California (see Mikel et al. 2007, City of San Diego 2010). The taxa characteristic of this mid-shelf assemblage included the ophiuroid *Amphiodia urtica*, juvenile *Amphiodia*, and the bivalve *Axinopsida serricata*. The sediments associated with this group were mixed, averaging 47% fines, and with an average TOC concentration of 0.9% wt.

Summary and Conclusions

The summer 2009 regional benthic survey was different than the previous regional surveys off San Diego (see City of San Diego 1999−2003, 2006−2008) in that it included samples from deep waters along the upper continental slope (200−500 m) as well as shelf habitats <200 m depth. Although soft-bottom benthic invertebrate communities often exhibit considerable spatial and temporal variability (e.g., Morrisey et al. 1992a, 1992b; Otway 1995), the general distribution and types of macrobenthic assemblages along the San Diego shelf have shown little net change since the regional

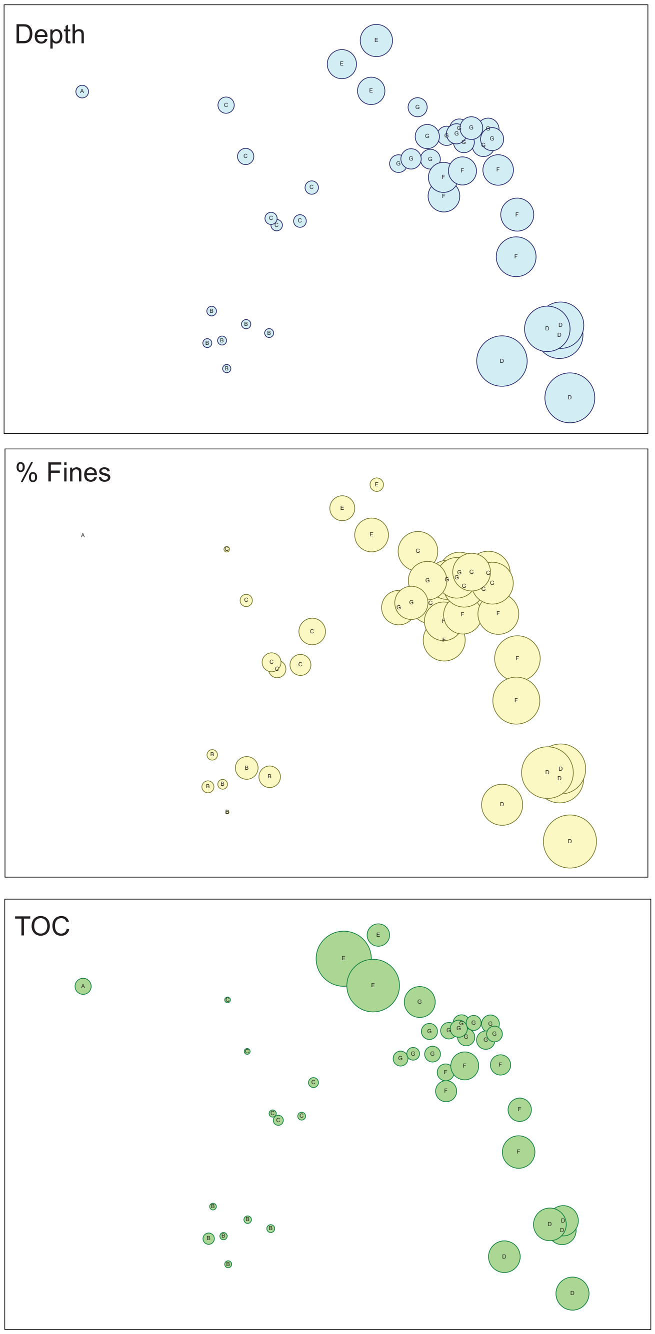


Figure 9.6
MDS ordination of macrofaunal abundance data for 2009 regional stations (see Figure 9.4), with superimposed circles representing station depth, and the amount of fine particles (% fines) and total organic carbon (TOC, % wt) in sediments. Circles vary in size according to the magnitude of each value.

surveys began. For example, the results of a cluster analysis of the same sites sampled in 1999 and 2009 showed that most stations clustered with or closely to their counterparts in both years. A more detailed comparison of the seven assemblage types described herein for 2009 with those reported for 1999 (see City of San Diego 2000) also indicated considerable similarity. Evaluation of differences in several important measures of benthic community structure (e.g., species richness, abundance, diversity, benthic response index) between the different depth strata over this time span was also indicative of long-term stability. Possible exceptions included disparities in species richness and abundance at mid-shelf depths, both of which were higher in 1999. It is unclear what may be the cause off these differences, although a major El Niño that occurred in 1998 could be responsible for an influx of typically more southern species into the region around that time. In contrast, it seems likely that the difference in abundances may reflect lower numbers than normal during 2009 as the pattern of higher abundances along the mid-shelf seen in 1999 is more typical for the SCB.

The SCB benthos has long been considered to be composed of "patchy" habitats, with the distribution of species and communities exhibiting considerable spatial variability. Results of the regional surveys off San Diego generally support this characterization. The 2009 benthic assemblages appeared to segregate primarily by habitat characteristics such as depth (i.e., strata) and sediment grain size, and were similar to those sampled in the past except for at the slope sites. About one-third of the benthos sampled off San Diego in 2009 was characterized by a mid-shelf, mixed sediment (i.e., 47% fines) assemblage dominated by the ophiuroid *Amphiodia urtica* (i.e., cluster group G). This assemblage corresponds to the *Amphiodia* "mega-community" described by Barnard and Ziesenhenne (1961), and is common in the Point Loma region off San Diego (e.g., City of San Diego 2010) as well as other parts of the southern California mainland shelf (e.g., Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993; Zmarzly et al. 1994, Diener and Fuller 1995, and Bergen et al. 1998, 2000, 2001).

Several distinct nearshore assemblages were also present off San Diego that were generally similar to those found in shallow, sandy sediment habitats in the SCB (see Barnard 1963, Jones 1969, Thompson et al. 1987, 1992; ES Engineering

Science 1988, Mikel et al. 2007). For example, the group B and C assemblages occurred at inner to shallow mid-shelf sites (11−43 m) characterized by coarse sediments averaging between 7−10% fines. Polychaetes such as *Owenia collaris* and *Spiophanes norrisi* were numerically dominant in these two assemblages. The single site that constituted the third shallow assemblage (group A) was characterized by even coarser sediments with no fines. This assemblage was dominated by the polychaetes *Spio maculata* and *Lumbrinerides platypygos*, and also contained several other species associated with very coarse sediments.

Two different assemblages were present along the outer shelf at depths between 122−177 m and at one deeper station (257 m) located near the top of the upper slope. The group E assemblage occurred along the Coronado Bank where sediments were relatively coarse (~19% fines). Species characteristic of this assemblage included the brittle star *Amphiodia digitata* and two cirratulids (i.e., *Monticellina siblina* and *Chaetozone* sp SD5). In contrast, the group F assemblage was characterized by several species of bivalve molluscs (e.g., *Tellina carpenteri*, *Adontorhina cylcia*, and *Axinopsida serricata*), and occurred in mixed sediments averaging 50% fines.

As expected, the upper slope represents a unique habitat off San Diego compared to shallower areas, with the macrofauna from the five deepest stations (335−413 m) clustering together as group D. Sediments at these sites had the highest percentage of fine particles averaging 70% fines. These sites were distinguished by considerably fewer species and lower abundances than along the shelf, while characteristic species included various species of molluscs such as the bivalves *Nuculana conceptionis* and *Ennucula tenuis*, and the scaphopod *Gadila tolmiei*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2009 regional survey that could be attributed to wastewater discharges, disposal sites or other point sources. Overall, benthic macrofauna appear to be in good condition throughout the region, with 94% of the sites surveyed in 2009 being in reference condition and the remaining 6% deviating only marginally based on assessments using the benthic response index (BRI). This is not unexpected as Ranasinghe et al. (2010) recently reported that 98% of the entire SCB was in good condition based on assessment data gathered during the 1994−2003 bight-wide surveys.

Literature Cited

Barnard, J.L. (1963). Relationship of benthic Amphipoda to invertebrate communities of inshore sublittoral sands of southern California. Pacific Naturalist, 3: 439–467.

Barnard, J.L. and F.C. Ziesenhenne. (1961). Ophiuroidea communities of southern Californian coastal bottoms. Pacific Naturalist, 2: 131–152.

Bergen, M. (1996). The Southern California Bight Pilot Project: Sampling Design, In: M.J. Allen, C. Francisco, D. Hallock. (eds.). Southern California Coastal Water Research Project: Annual Report 1994–1995. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull, R.G. Velarde, and S.B. Weisberg. (2000). Assessment of benthic infaunal condition on the mainland shelf of southern California. Environmental Monitoring and Assessment, 64: 421–434.

Bergen, M., S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, R.W. Smith, J.K. Stull, and R.G. Velarde. (1998). Southern California Bight 1994 Pilot Project: IV. Benthic Infauna. Southern California Coastal Water Research Project, Westminster, CA.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K.

Stull, R.G. Velarde, and J.A. Ranasinghe. (2001). Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138: 637–647.

City of San Diego. (1999). San Diego Regional Monitoring Report for 1994–1997. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2000). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 1999. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2001). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2000. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2002). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall, 2001. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2003). Annual Receiving Waters Monitoring Report for the City of San Diego South Bay Water Reclamation Plant Discharge to the Pacific Ocean through the South Bay Ocean Outfall, 2002. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2006). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2005. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2007). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2006. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2008). Annual Receiving Waters Monitoring Report for the South Bay Ocean Outfall (South Bay Water Reclamation Plant), 2007. City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

City of San Diego. (2010). Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2009. City of San Diego Ocean Monitoring Program, Public Utilities Department, Environmental Monitoring and Technical Services Division, San Diego, CA.

Clarke, K.R. (1993). Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117–143.

Clarke, K.R. and M. Ainsworth. (1993). A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series 92: 205–209.

Clarke, K.R. and R.N. Gorley. (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.

Clarke, K.R., P.J. Somerfield, and R.N. Gorley. (2008). Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. Journal of Experimental Marine Biology and Ecology, 366: 56–69.

Diener, D.R. and S.C. Fuller. (1995). Infaunal patterns in the vicinity of a small coastal wastewater outfall and the lack of infaunal community response to secondary treatment. Bulletin of the Southern California Academy of Science, 94: 5–20.

Diener, D.R., S.C. Fuller, A. Lissner, C.I. Haydock, D. Maurer, G. Robertson, and R. Gerlinger. (1995). Spatial and temporal patterns of the infaunal community near a major ocean outfall in southern California. Marine Pollution Bulletin, 30: 861–878.

ES Engineering Science, Inc. (1988). Tijuana Oceanographic Engineering Study (TOES) Ocean Measurement Program Summary Phases I–III (May 1986–December 1988). ES Engineering Science, Inc., San Diego, CA.

Fauchald, K. and G.F. Jones. (1979). Variation in community structures on shelf, slope, and basin macrofaunal communities of the Southern California Bight. Report 19, Series 2. In: Southern California Outer Continental Shelf Environmental Baseline Study, 1976/1977 (Second Year) Benthic Program. Principal Investigators Reports, Vol. II. Science Applications, Inc. La Jolla, CA.

Ferraro, S.P., R.C. Swartz, F.A. Cole, and W.A. Deben. (1994). Optimum macrobenthic sampling protocol for detecting pollution impacts in the Southern California Bight. Environmental Monitoring and Assessment, 29: 127–153.

Field, J.G., K.R. Clarke, and R.M. Warwick. (1982). A practical strategy for analyzing multiple species distribution patterns. Marine Ecology Progress Series, 8: 37–52.

Hyland, J.L., W.L. Balthis, V.D. Engle, E.R. Long, J.F. Paul, J.K. Summers, R.F. Van Dolah. (2003). Incidence of stress in benthic communities along the US Atlantic and Gulf of Mexico coasts within different ranges of sediment contamination from chemical mixtures. Environmental Monitoring and Assessment, 81: 149–161.

Jones, G.F. (1969). The benthic macrofauna of the mainland shelf of southern California. Allan Hancock Monographs of Marine Biology, 4: 1–219.

Mikel T.K., J.A Ranasinghe, and D.E. Montagne. (2007). Characteristics of benthic macrofauna of the Southern California Bight. Appendix F. Southern California Bight 2003 Regional Monitoring Program.

Morrisey, D.J., L. Howitt, A.J. Underwood, and J.S. Stark. (1992a). Spatial variation in soft-sediment benthos. Marine Ecology Progress Series, 81: 197–204.

Morrisey, D.J., A.J. Underwood, L. Howitt, and J.S. Stark. (1992b). Temporal variation in soft-sediment benthos. Journal of Experimental Marine Biology and Ecology, 164: 233–245.

Otway, N.M. (1995). Assessing impacts of deepwater sewage disposal: a case study from New South Wales, Australia. Marine Pollution Bulletin, 31: 347–354.

Ranasinghe, J.A., A.M. Barnett, K. Schiff, D.E. Montagne, C. Brantley, C. Beegan, D.B. Cadien, C. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts, and S.B. Weisberg. (2007). Southern California Bight 2003 Regional Monitoring Program: III. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA.

Ranasinghe, J.A., D. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D. Cadien, R. Velarde, and A. Dalkey. (2003). Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Southern California Coastal Water Research Project. Westminster, CA.

Ranasinghe, J.A., K.C. Schiff, D.E. Montagne, T.K. Mikel, D.B. Cadien, R.G. Velarde, and C.A. Brantley. (2010). Benthic macrofaunal community condition in the Southern

California Bight, 1994–2003. Marine Pollution Bulletin, 60: 827–833.

Smith, R.W., M. Bergen, S.B. Weisberg, D. Cadien, A. Dalkey, D. Montagne, J.K. Stull, and R.G. Velarde. (2001). Benthic response index for assessing infaunal communities on the southern California mainland shelf. Ecological Applications, 11(4): 1073–1087.

Stevens Jr., D.L. (1997). Variable density grid-based sampling designs for continuous spatial populations. Environmetrics, 8: 167–195.

Stevens Jr., D.L. and A.R. Olsen (2004). Spatially-balanced sampling of natural resources in the presence of frame imperfections. Journal of the American Statistical Association, 99: 262–278.

Stull, J.K. (1995). Two decades of marine environmental monitoring, Palos Verdes, California, 1972–1992. Bulletin of the Southern California Academy of Sciences, 94: 21–45.

Stull, J.K., C.I. Haydock, R.W. Smith, and D.E. Montagne. (1986). Long-term changes in the benthic community on the coastal shelf of Palos Verdes, southern California. Marine Biology, 91: 539–551.

Stull, J.K., D.J.P. Swift, and A.W. Niedoroda (1996). Contaminant dispersal on the Palos Verdes continental margin: I. Sediments and biota near a major California wastewater discharge. Science of the Total Environment, 179: 73–90.

Swartz, R.C., F.A. Cole, and W.A. Deben. (1986). Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series, 31: 1–13.

Thompson, B.E., J. Dixon, S. Schroeter, and D.J. Reish. (1993). Chapter 8. Benthic invertebrates. In: M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). Ecology of the Southern California Bight: A Synthesis and Interpretation. University of California Press, Berkeley, CA. p 369–458.

Thompson, B., J.D. Laughlin, and D.T. Tsukada. (1987). 1985 Reference Site Survey. Technical Report No. 221, Southern California Coastal Water Research Project, Long Beach, CA.

Thompson, B., D. Tsukada, and D. O'Donohue. (1992). 1990 Reference Survey. Technical Report No. 355, Southern California Coastal Water Research Project, Long Beach, CA.

[U.S. EPA] United States Environmental Protection Agency. (1987). Quality Assurance and Quality Control (QA/QC) for 301(h) Monitoring Programs: Guidance on Field and Laboratory Methods. EPA Document 430/9-86-004. Office of Marine and Estuarine Protection.

[U.S. EPA] United States Environmental Protection Agency. (2004). National Coastal Condition Report II. US Environmental Protection Agency, Office of Research and Development, EPA-620/R-03/002, Washington, DC, USA.

Warwick, R.M. (1993). Environmental impact studies on marine communities: pragmatical considerations. Australian Journal of Ecology, 18: 63–80.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan, and K.L. Barwick. (1994). Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: relation to anthropogenic and natural events. Marine Biology, 118: 293–307.

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Glossary

GLOSSARY

Absorption
The movement of dissolved substances (e.g., pollution) into cells by diffusion.

Adsorption
The adhesion of dissolved substances to the surface of sediment or on the surface of an organism (e.g., a flatfish).

Anthropogenic
Made and introduced into the environment by humans, especially pertaining to pollutants.

Assemblage
An association of interacting populations in a given habitat (e.g., an assemblage of benthic invertebrates on the ocean floor).

BACIP Analysis
An analytical tool used to assess environmental changes caused by the effects of pollution. A statistical test is applied to data from matching pairs of control and impacted sites before and after an event (i.e., initiation of wastewater discharge) to test for significant change. Significant differences are generally interpreted as being the result of the environmental change attributed to the event. Variation that is not significant reflects natural variation.

Benthic
Pertaining to the environment inhabited by organisms living on or in the ocean bottom.

Benthos
Living organisms (e.g., algae and animals) associated with the sea bottom.

Bioaccumulation
The process by which a chemical becomes accumulated in tissue over time through direct intake of contaminated water, the consumption of contaminated prey, or absorption through the skin or gills.

Biota
The living organisms within a habitat or region.

BOD
Biochemical oxygen demand (BOD) is the amount of oxygen consumed (through biological or chemical processes) during the decomposition of organic material contained in a water or sediment sample. It is a measure for certain types of organic pollution, such that high BOD levels suggest elevated levels of organic pollution.

BRI
The benthic response index (BRI) measures levels of environmental disturbance by assessing the condition of a benthic assemblage. The index was based on organisms found in the soft sediments of the Southern California Bight (SCB).

CFU
The colony-forming unit (CFU) is the bacterial cell or group of cells which reproduce on a plate and result in a visible colony that can be quantified as a measurement of density; it is often used to estimate bacteria concentrations in ocean water.

Control site
A geographic location that is far enough from a known pollution source (e.g., ocean outfall) to be considered representative of an undisturbed environment. Data collected from control sites are used as a reference and compared to impacted sites.

COP
The California Ocean Plan (COP) is California's ocean water quality control plan. It limits wastewater discharge and implements ocean monitoring. Federal law requires the plan to be reviewed every three years.

Crustacea
A group (subphylum) of marine invertebrates characterized by jointed legs and an exoskeleton (e.g., crabs, shrimp, and lobster).

CTD
A device consisting of a group of sensors that continually measure various physical and chemical properties such as conductivity (a proxy for salinity), temperature, and pressure (a proxy for depth) as it

is lowered through the water. These parameters are used to assess the physical ocean environment.

Demersal
Organisms living on or near the bottom of the ocean and capable of active swimming.

Dendrogram
A tree-like diagram used to represent hierarchal relationships from a multivariate analysis where results from several monitoring parameters are compared among sites.

Detritus
Particles of organic material from decomposing organisms. Used as an important source of nutrients in a food web.

Diversity
A measurement of community structure which describes the abundances of different species within a community, taking into account their relative rarity or commonness.

Dominance
A measurement of community structure that describes the minimum number of species accounting for 75% of the abundance in each grab.

Echinodermata
A group (phylum) of marine invertebrates characterized by the presence of spines, a radially symmetrical body, and tube feet (e.g., sea stars, sea urchins, and sea cucumbers).

Effluent
Wastewater that flows out of a sewer, treatment plant outfall, or other point source and is discharged into a water body (e.g. ocean, river).

FIB
Fecal indicator bacteria (FIB) are the bacteria (total coliform, fecal coliform, and enterococcus) measured and evaluated to provide information about the movement and dispersion of wastewater discharged to the Pacific Ocean through the outfall.

Halocline
A vertical zone of water in which the salinity changes rapidly with depth.

Impact site
A geographic location that has been altered by the effects of a pollution source, such as a wastewater outfall.

Indicator species
Marine invertebrates whose presence in the community reflects the health of the environment. The loss of pollution-sensitive species or the introduction of pollution-tolerant species can indicate anthropogenic impact.

Infauna
Animals living in the soft bottom sediments usually burrowing or building tubes within.

Invertebrate
An animal without a backbone (e.g., sea star, crab, and worm).

Kurtosis
A measure that describes the shape (i.e., peakedness or flatness) of distribution relative to a normal distribution (bell shape) curve. Kurtosis can indicate the range of a data set, and is used herein to describe the distribution of particle sizes within sediment samples.

Macrobenthic invertebrate
Epifaunal or infaunal benthic invertebrates that are visible with the naked eye. This group typically includes those animals larger than meiofauna and smaller than megafauna. These animals are collected in grab samples from soft-bottom marine habitats and retained on a 1-mm mesh screen.

MDL
The EPA defines MDL (method detection limit) as "the minimum concentration that can be determined with 99% confidence that the true concentration is greater than zero."

Megabenthic invertebrate
A larger, usually epibenthic and motile, bottom-dwelling animal such as a sea urchin, crab, or snail. These animals are typically collected by otter trawl nets with a minimum mesh size of 1 cm.

Mollusca
A taxonomic group (phylum) of invertebrates characterized as having a muscular foot, visceral mass, and a shell. Examples include snails, clams, and octupuses.

Motile
Self-propelled or actively moving.

Niskin bottle
A long plastic tube allowing seawater to pass through until the caps at both ends are triggered to close from the surface. They often are arrayed with several others in a rosette sampler to collect water at various depths.

Non-point source
Pollution sources from numerous points, not a specific outlet, generally carried into the ocean by storm water runoff.

NPDES
The National Pollutant Discharge Elimination System (NPDES) is a federal permit program that controls water pollution by regulating point sources that discharge pollutants into waters of the United States.

Ophiuroidea
A taxonomic group (class) of echinoderms that comprises the brittle stars. Brittle stars usually have five long, flexible arms and a central disk-shaped body.

PAHs
The USGS defines polycyclic aromatic hydrocarbons (PAHs) as, "hydrocarbon compounds with multiple benzene rings. PAHs are typical components of asphalts, fuels, oils, and greases."

PCBs
The EPA defines polychlorinated biphenyls (PCBs) as, "a category, or family, of chemical compounds formed by the addition of chlorine (C_{12}) to biphenyl ($C_{12}H_{10}$), which is a dual-ring structure comprising two 6-carbon benzene rings linked by a single carbon-carbon bond."

PCB Congeners
The EPA defines a PCB congener as, "one of the 209 different PCB compounds. A congener may have between one and 10 chlorine atoms, which may be located at various positions on the PCB molecule."

Phi
The conventional unit of sediment size based on the log of sediment grain diameter. The larger the phi number, the smaller the grain size.

Plankton
Animal and plant-like organisms, usually microscopic, that are passively carried by ocean currents.

PLOO
The Point Loma Ocean Outfall (PLOO) is the underwater pipe originating at the Point Loma Wastewater Treatment Plant and used to discharge treated wastewater. It extends 7.2 km (4.5 miles) offshore and discharges into 96 m (320 ft) of water.

Point source
Pollution discharged from a single source (e.g., municipal wastewater treatment plant, storm drain) to a specific location through a pipe or outfall.

Polychaeta
A taxonomic group (class) of invertebrates characterized as having worm-like features, segments, and bristles or tiny hairs. Examples include bristle worms and tube worms.

Pycnocline
A depth zone in the ocean where sea water density changes rapidly with depth and typically is associated with a decline in temperature and increase in salinity.

Recruitment
The retention of young individuals into the adult population in an open ocean environment.

Relict sand
Coarse reddish-brown sand that is a remnant of a pre-existing formation after other parts have disappeared. Typically originating from land and transported to the ocean bottom through erosional processes.

Rosette sampler
A device consisting of a round metal frame housing a CTD in the center and multiple bottles (see Niskin bottle) arrayed about the perimeter. As the instrument is lowered through the water column, continuous measurements of various physical and chemical parameters are recorded by the CTD. Discrete water samples are captured at desired depths by the bottles.

SBOO
The South Bay Ocean Outfall (SBOO) is the underwater pipe originating at the International Wastewater Treatment Plant and used to discharge treated wastewater. It extends 5.6 km (3.5 miles) offshore and discharges into about 27 m (90 ft) of water.

SBWRP
The South Bay Water Reclamation Plant (SBWRP) provides local wastewater treatment services and reclaimed water to the South Bay. The plant began operation in 2002 and has a wastewater treatment capacity of 15 million gallons a day.

SCB
The Southern California Bight (SCB) is the geographic region that stretches from Point Conception, U.S.A. to Cabo Colnett, Mexico and encompasses nearly 80,000 km^2 of coastal land and sea.

Shell hash
Sediments composed of shell fragments.

Skewness
A measure of the lack of symmetry in a distribution or data set. Skewness can indicate where most of the data lies within a distribution. It can be used to describe the distribution of particle sizes within sediment grain size samples.

Sorting
The range of grain sizes that comprises marine sediments. Also refers to the process by which sediments of similar size are naturally segregated during transport and deposition according to the velocity and transporting medium. Well sorted sediments are of similar size (such as desert sand), while poorly sorted sediments have a wide range of grain sizes (as in a glacial till).

Species richness
The number of species per sample or unit area. A metric used to evaluate the health of macro-benthic communities.

Standard length
The measurement of a fish from the most forward tip of the body to the base of the tail (excluding the tail fin rays). Fin rays can sometimes be eroded by pollution or preservation so measurement that includes them (i.e., total length) is considered less reliable.

Thermocline
The zone in a thermally stratified body of water that separates warmer surface water from colder deep water. At a thermocline, temperature changes rapidly over a short depth.

Tissue burden
The total amount of measured chemicals that are present in the tissue (e.g. fish muscle).

Transmissivity
A measure of water clarity based upon the ability of water to transmit light along a straight path. Light that is scattered or absorbed by particulates (e.g., plankton, suspended solid materials) decreases the transmissivity (or clarity) of the water.

Upwelling
The movement of nutrient-rich and typically cold water from the depths of the ocean to the surface waters.

USGS
The United States Geological Survey (USGS) provides geologic, topographic, and hydrologic information on water, biological, energy, and mineral resources.

Van Dorn bottle
A water sampling device made of a plastic tube open at both ends that allows water to flow through. Rubber caps at the tube ends can be triggered to close underwater to collect water at a specified depth.

Van Veen grab
A mechanical device designed to collect ocean sediment samples. The device consists of a pair of hinged jaws and a release mechanism that allows the opened jaws to close and entrap a 0.1 m^2 sediment sample once the grab touches bottom.

Wastewater
A mixture of water and waste materials originating from homes, businesses, industries, and sewage treatment plants.

ZID
The zone of initial dilution (ZID) is the region of initial mixing of the surrounding receiving waters with wastewater from the diffuser ports of an outfall. This area includes the underlying seabed. In the ZID, the environment is chronically exposed to pollutants and often is the most impacted.

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Appendices

Appendix A

Supporting Data

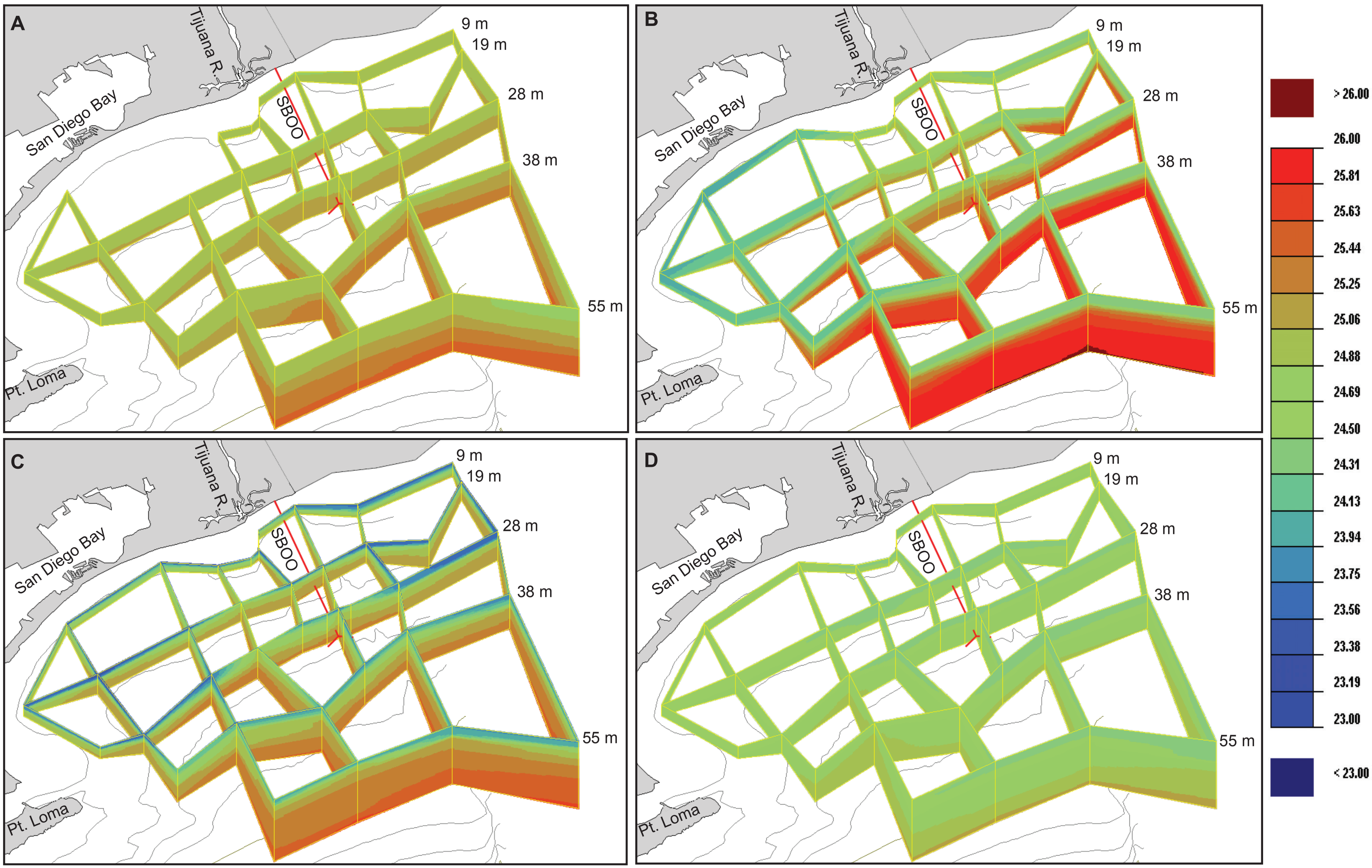
2009 SBOO Stations

Oceanographic Conditions

Appendix A.1

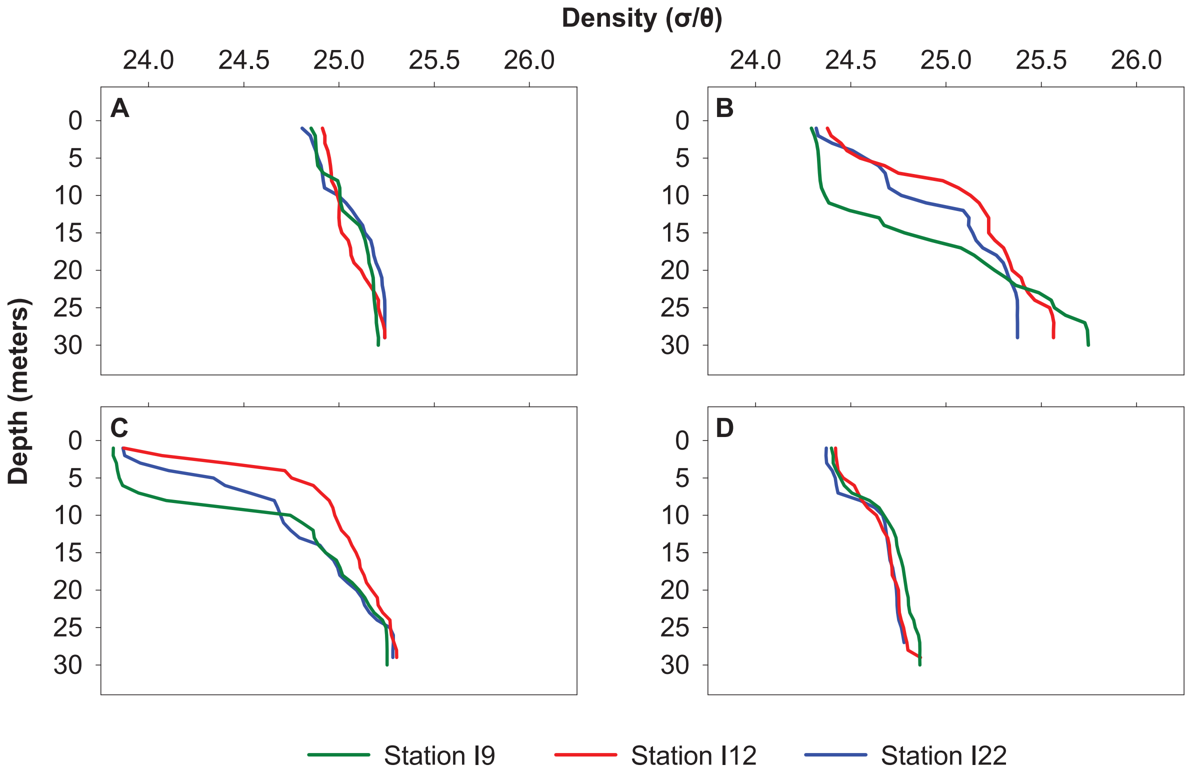
Summary of the dates CTD casts were conducted during 2009. Stations were sampled monthly, usually over a 3-day period. This included 11 stations sampled on the day designated “North WQ” (stations I28–I38), 15 stations sampled on the day designated “Mid WQ” (stations I12, I14–I19, I22–I27, I39, I40), and 14 stations sampled on the day designated “South WQ” (stations I1–I11, I13, I20, I21).

	2009 Sample Dates											
Sample Group	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
North WQ	8	4	6	6	15	12	9	12	17	7	12	11
Mid WQ	7	2	2	8	11	8	6	10	16	5	9	18
South WQ	6	3	4	7	13	11	8	11	18	6	10	10



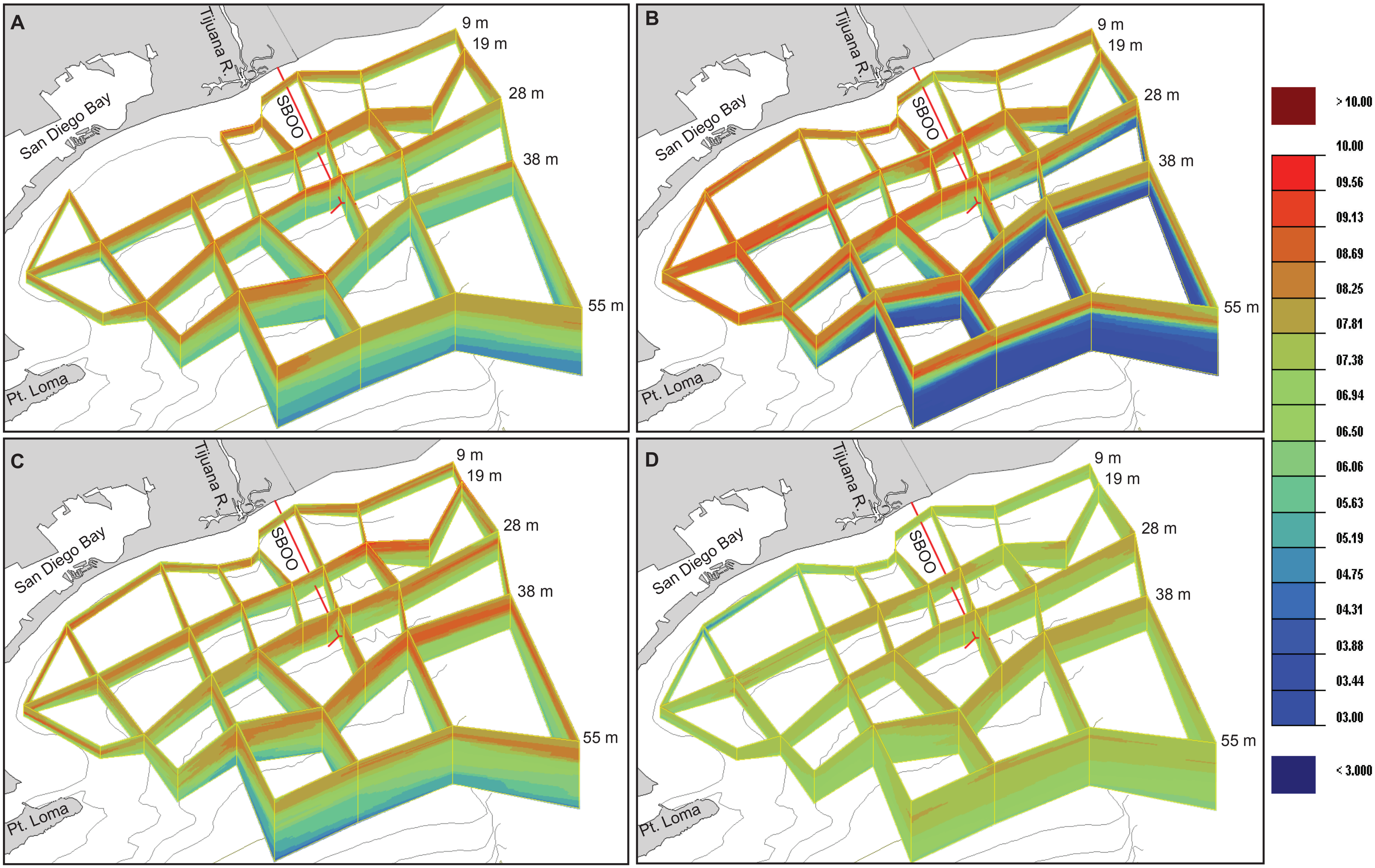
Appendix A.2

Ocean density (σ/θ) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.



Appendix A.3

Vertical profiles of density for SBOO stations I9, I12 and I22 during February (A), May (B), August (C), and November (D) 2009.



Appendix A.4

Concentrations of dissolved oxygen (mg/L) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

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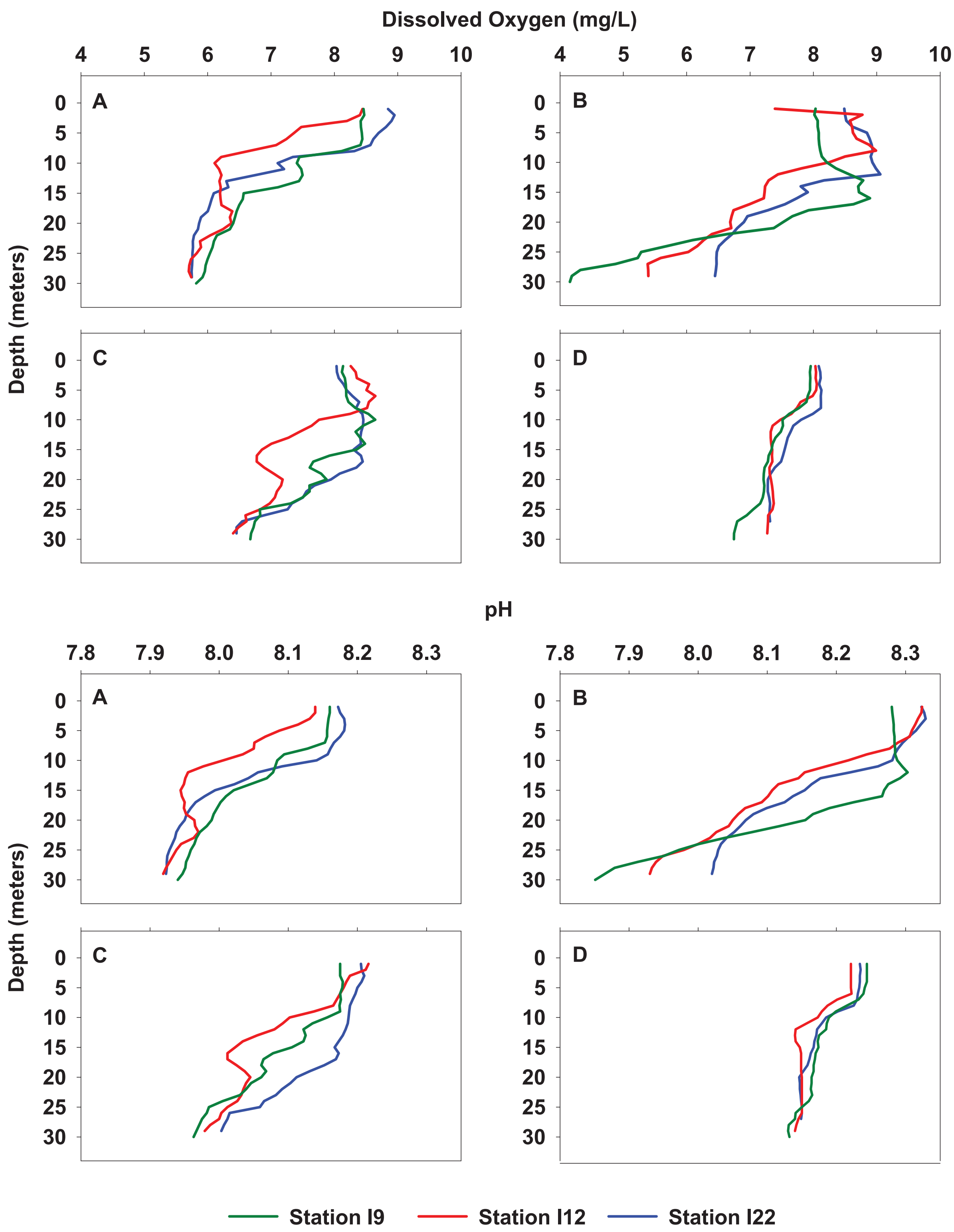
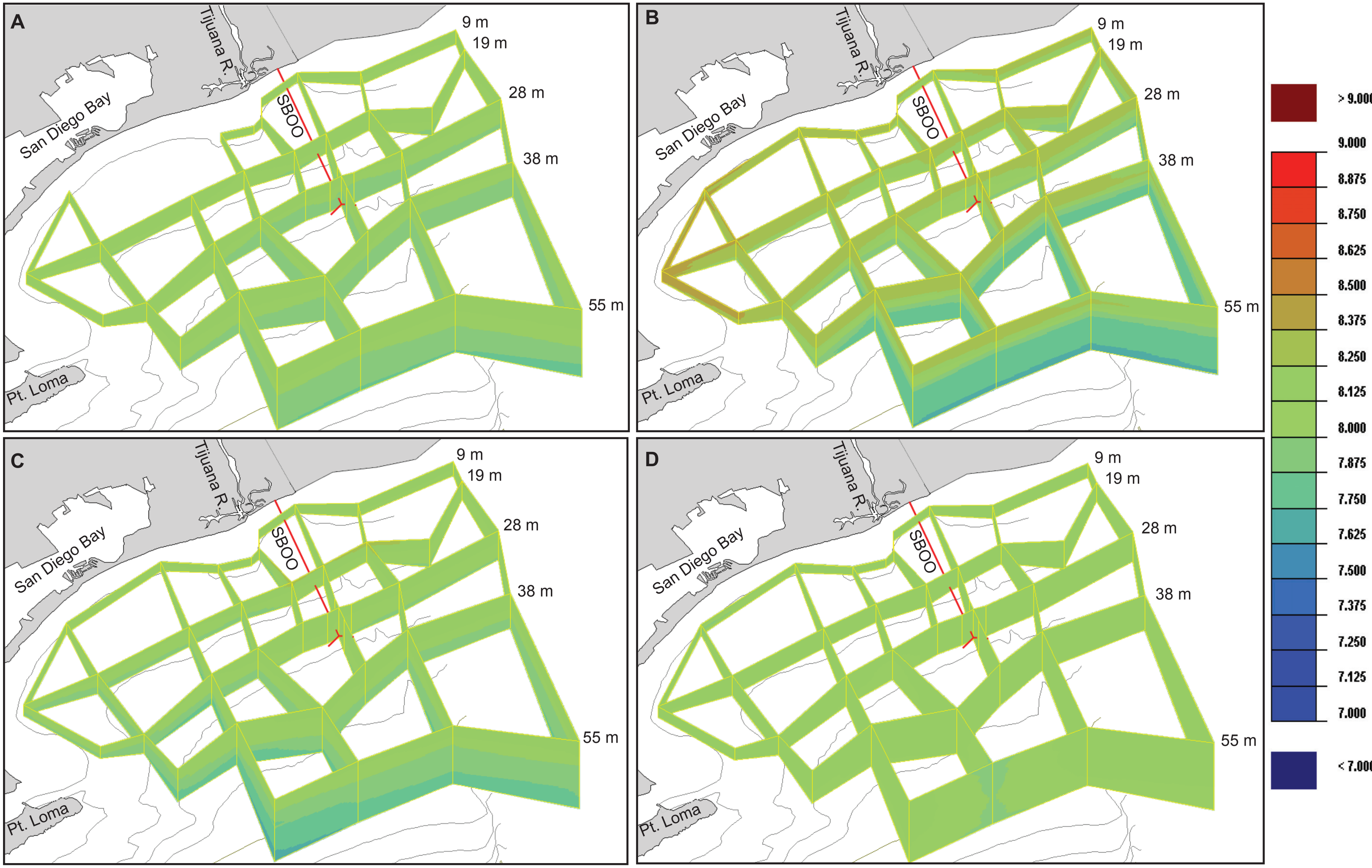


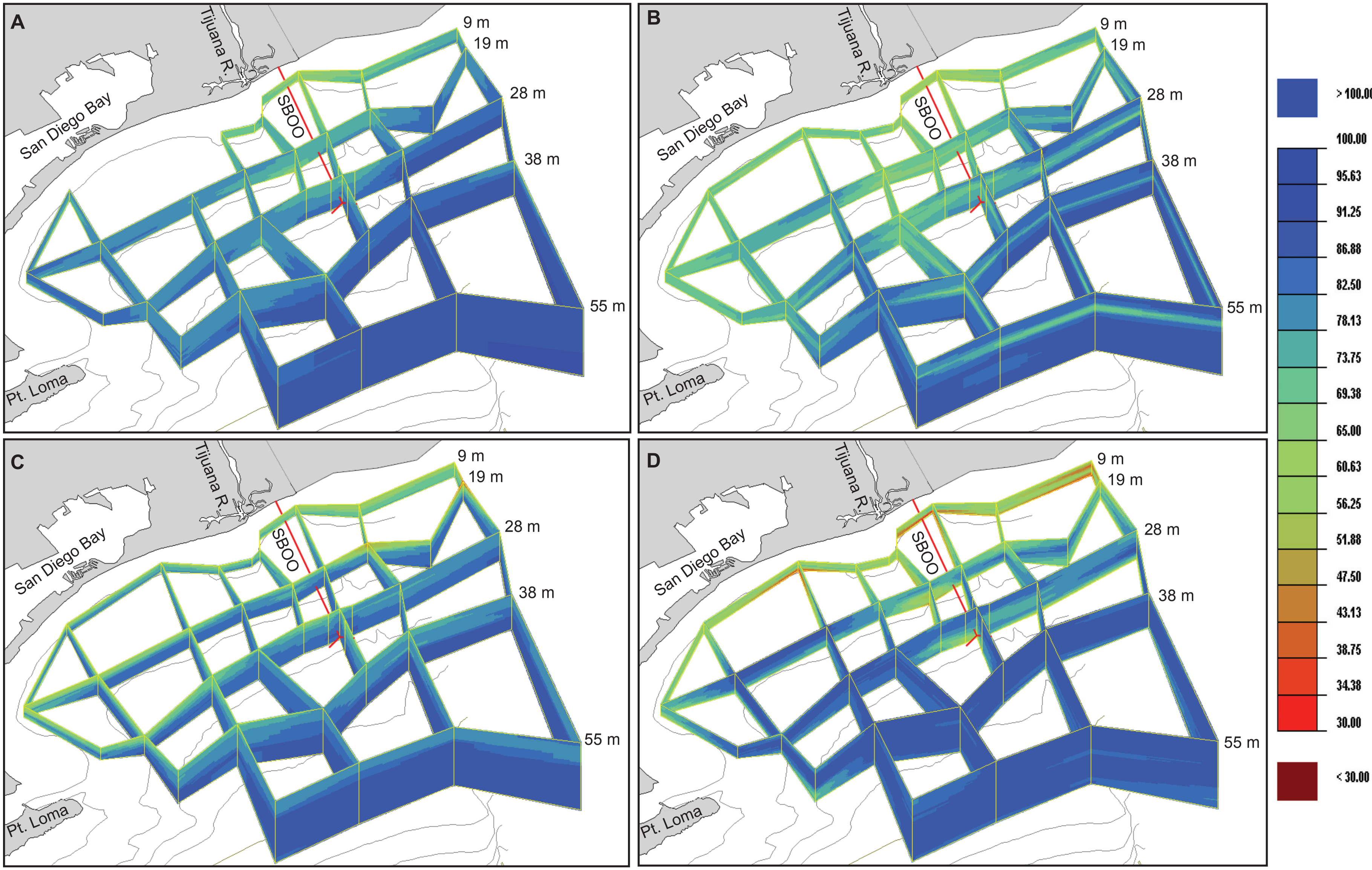
Appendix A.5

Vertical profiles of dissolved oxygen and pH for SBOO stations I9, I12 and I22 during February (A), May (B), August (C), and November (D) 2009.



Appendix A.6

Levels of pH recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.



Appendix A.7

Transmissivity (%) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

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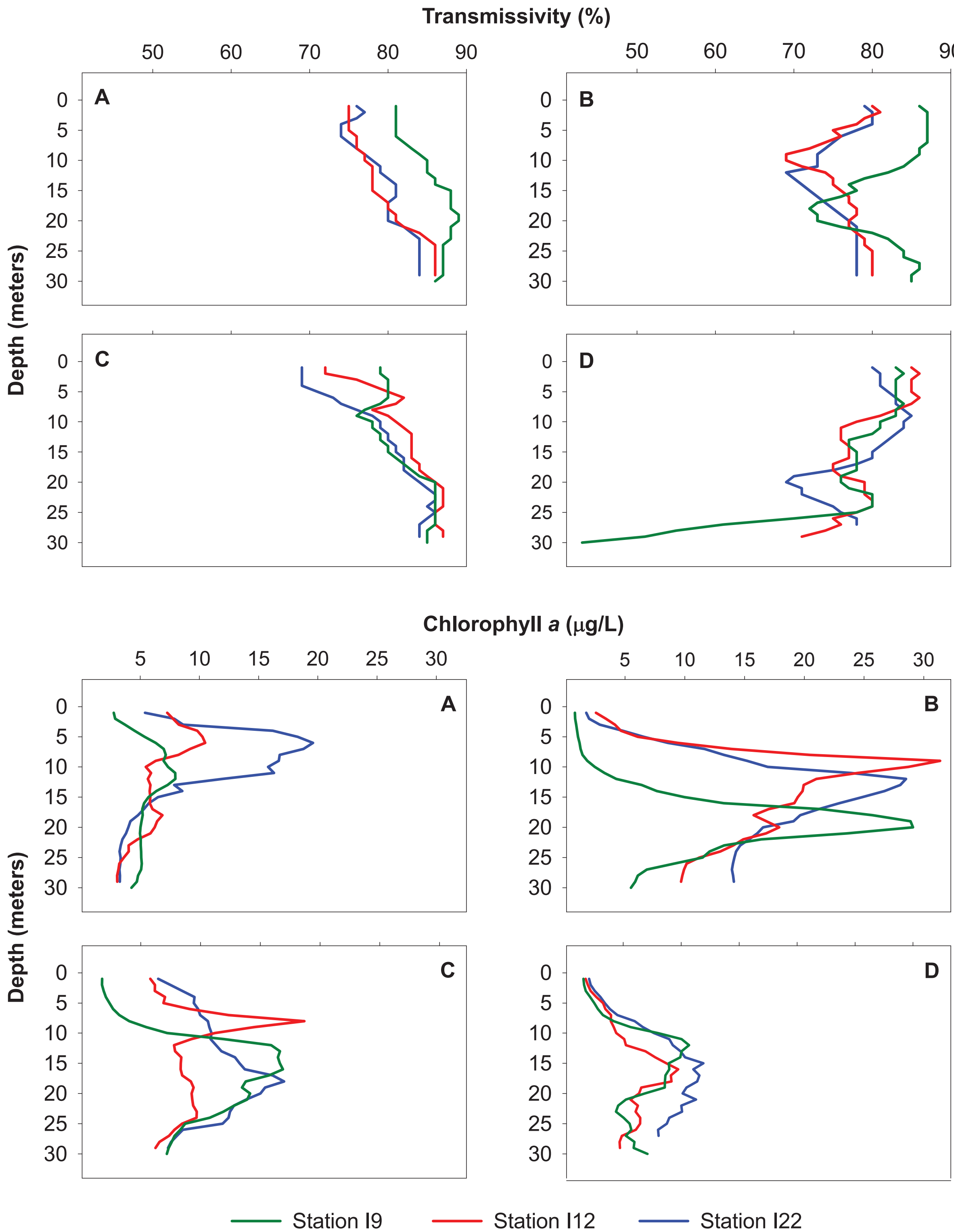

Appendix A.8

Vertical profiles of transmissivity and chlorophyll *a* for SBOO stations I9, I12 and I22 during February (A), May (B), August (C), and November (D) 2009.

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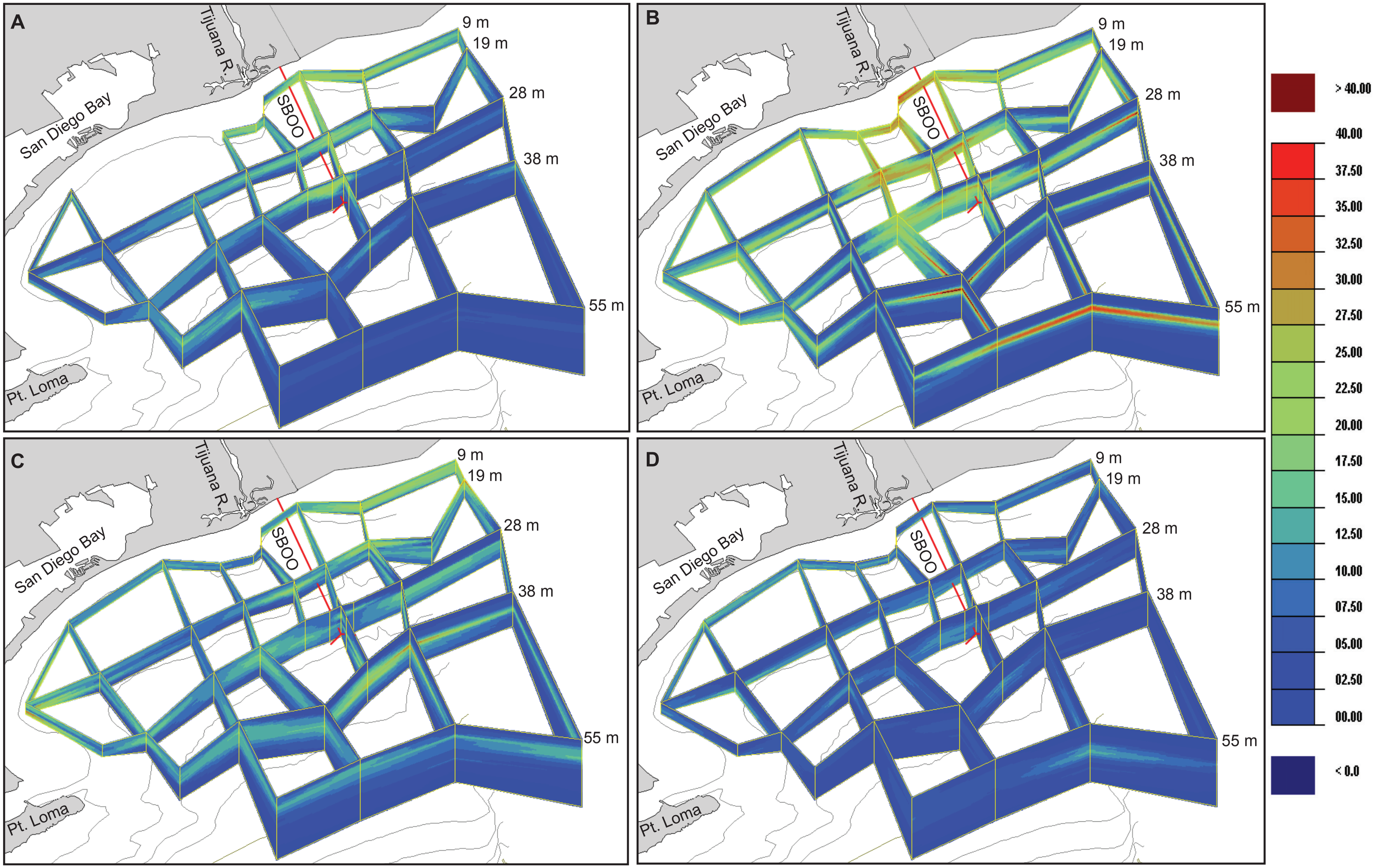

Appendix A.9

Concentrations of chlorophyll *a* (µg/L) recorded in 2009 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

Appendix B

Supporting Data

2009 SBOO Stations

Water Quality

Appendix B.1

Summary of rainfall and bacteria levels at shore stations in the SBOO region during 2009. Rain data are from Lindbergh Field, San Diego, CA. Total coliform (Total), fecal coliform (Fecal), and enterococcus (Entero) densities are expressed as mean CFU/100 mL per month and for the entire year. Stations are listed north to south from left to right.

Month	Rain (in)		S9	S8	S12	S6	S11	S5	S10	S4	S3	S2	S0
Jan	0.08	*Total*	16	46	407	4019	4057	8151	13,350	6205	4320	375	2690
		Fecal	7	5	47	253	811	6051	3490	2579	527	42	136
		Entero	2	3	12	52	141	4211	356	211	60	59	110
Feb	2.63	*Total*	261	4006	4106	4201	4341	12,050	7305	3190	6855	5352	4806
		Fecal	32	1102	956	2219	2219	9012	2980	300	326	236	279
		Entero	8	1055	2515	1515	2310	7025	3374	586	2551	801	382
Mar	0.18	*Total*	11	16	20	30	70	4045	4011	4023	4016	81	2656
		Fecal	6	2	7	7	4	3003	502	1656	2053	10	168
		Entero	2	2	3	4	9	3004	11	17	107	22	81
Apr	0.14	*Total*	17	6	16	3245	3205	3328	153	101	85	14	1630
		Fecal	2	6	2	1043	2002	2408	5	8	4	3	97
		Entero	4	2	2	52	150	2631	2	4	5	34	39
May	0.04	*Total*	62	66	26	21	16	72	16	57	18	11	341
		Fecal	3	10	21	3	4	6	3	4	3	2	36
		Entero	2	2	8	9	17	25	6	5	7	3	25
Jun	0.03	*Total*	52	168	56	24	56	96	16	16	17	14	76
		Fecal	4	46	6	3	4	12	3	3	3	2	8
		Entero	2	8	5	7	6	13	3	2	4	2	2
Jul	0.00	*Total*	200	50	35	265	61	140	62	65	31	16	1766
		Fecal	17	4	10	8	12	6	7	4	5	2	207
		Entero	20	5	11	33	20	48	8	8	18	3	42
Aug	Trace	*Total*	20	65	106	61	61	11	106	153	16	26	381
		Fecal	2	3	2	2	3	3	6	7	7	3	32
		Entero	5	2	2	2	2	3	18	16	8	3	5
Sep	Trace	*Total*	40	52	92	84	56	20	88	52	9	50	92
		Fecal	6	2	8	27	2	4	3	2	4	6	10
		Entero	3	2	15	15	2	2	4	7	12	20	8
Oct	Trace	*Total*	16	16	22	16	11	20	12	20	11	63	21
		Fecal	4	3	5	2	2	2	2	3	3	3	4
		Entero	4	2	3	8	7	4	12	10	14	10	10
Nov	0.12	*Total*	31	9	12	22	11	65	7	11	22	2	481
		Fecal	3	2	2	6	2	2	2	2	9	2	122
		Entero	15	3	2	102	3	2	4	2	3	3	47
Dec	2.28	*Total*	120	3300	6416	5448	3420	7564	10,044	10,884	10,208	7236	7840
		Fecal	12	402	400	303	418	4072	1362	2408	448	953	974
		Entero	19	1043	869	779	1312	4872	1422	2541	1659	2495	1172
		n	52	52	52	52	52	52	52	52	52	52	52
Annual Means		*Total*	69	668	997	1510	1311	2947	2903	2119	2168	1159	1937
		Fecal	8	131	121	324	468	2016	670	583	270	116	180
		Entero	7	184	282	215	334	1825	429	311	374	315	171

Appendix B.2

Summary of samples with elevated (bold) total coliform (> 1000 CFU/100 mL), fecal coliform (> 400 CFU/100 mL), and/or enterococcus (> 104 CFU/100 mL) densities collected at SBOO shore stations during 2009. Bold F:T values are samples collected in 2009 which meet the FTR criteria for contamination (Total ≥1000 CFU/100 mL and F:T ≥0.10). Values are expressed as CFU/100 mL; Total = total coliform; Fecal = fecal coliform; Entero = enterococcus; F:T = fecal to total coliform ratio.

Station	Date	Total	Fecal	Entero	F:T
S5	06 Jan 2009	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	06 Jan 2009	**>16,000**	**1000**	**180**	0.06
S10	06 Jan 2009	**>16,000**	**1100**	**110**	0.07
S11	06 Jan 2009	**>16,000**	**3200**	**540**	**0.20**
S12	06 Jan 2009	**1600**	180	38	**0.11**
S2	13 Jan 2009	200	72	**180**	0.36
S3	13 Jan 2009	**2000**	**860**	46	**0.43**
S4	13 Jan 2009	**6800**	**3800**	**140**	**0.56**
S10	13 Jan 2009	**>16,000**	**6600**	**280**	**0.41**
S0	20 Jan 2009	**7000**	130	**140**	0.02
S4	20 Jan 2009	**2000**	100	60	0.05
S5	20 Jan 2009	**>16,000**	**>12,000**	**4800**	**0.75**
S10	20 Jan 2009	**>16,000**	**6000**	**980**	**0.38**
S0	28 Jan 2009	**2800**	300	**220**	**0.11**
S2	28 Jan 2009	**1200**	80	40	0.07
S3	28 Jan 2009	**15,000**	**1200**	**160**	0.08
S4	28 Jan 2009	**>16,000**	**6400**	**640**	**0.40**
S10	28 Jan 2009	**5400**	260	52	0.05
S5	03 Feb 2009	**>16,000**	**>12,000**	**3800**	**0.75**
S0	10 Feb 2009	**>16,000**	**980**	**1300**	0.06
S2	10 Feb 2009	**14,000**	**420**	**1200**	0.03
S3	10 Feb 2009	**4400**	80	**400**	0.02
S4	10 Feb 2009	**6000**	**580**	**600**	**0.10**
S5	10 Feb 2009	200	46	**300**	0.23
S10	10 Feb 2009	**>16,000**	**11,000**	**>12,000**	**0.69**
S0	17 Feb 2009	**3200**	130	**220**	0.04
S2	17 Feb 2009	**7400**	**520**	**2000**	0.07
S3	17 Feb 2009	**10,000**	**620**	**2600**	**0.06**
S4	17 Feb 2009	**6200**	**460**	**1600**	0.07
S5	17 Feb 2009	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	17 Feb 2009	**>16,000**	**8600**	**6000**	**0.54**
S8	17 Feb 2009	**>16,000**	**4400**	**4200**	**0.28**
S9	17 Feb 2009	1000	120	20	**0.12**
S10	17 Feb 2009	**11,000**	**580**	**1400**	0.05
S11	17 Feb 2009	**>16,000**	**8400**	**9200**	**0.53**
S12	17 Feb 2009	**>16,000**	**3800**	**10,000**	**0.24**
S3	24 Feb 2009	**13,000**	**600**	**7200**	0.05
S4	24 Feb 2009	520	120	**140**	0.23
S5	24 Feb 2009	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10	24 Feb 2009	**2200**	320	92	**0.15**
S11	24 Feb 2009	**1200**	**460**	4	**0.38**
S3	03 Mar 2009	**>16,000**	**8200**	**360**	**0.51**
S4	03 Mar 2009	**>16,000**	**6600**	50	**0.41**
S5	03 Mar 2009	**>16,000**	**>12,000**	**>12,000**	**0.75**
S10	03 Mar 2009	**>16,000**	**2000**	30	**0.13**
S0	10 Mar 2009	**10,000**	**480**	88	0.05

Appendix B.2 *continued*

Station	Date	Total	Fecal	Entero	F:T
S0	24 Mar 2009	320	160	**180**	0.50
S2	14 Apr 2009	10	6	**160**	0.60
S5	14 Apr 2009	**>16,000**	**>12,000**	**13,000**	**0.75**
S6	14 Apr 2009	**>16,000**	**5200**	**240**	**0.33**
S11	14 Apr 2009	**>16,000**	**10,000**	**740**	**0.63**
S0	28 Apr 2009	**8000**	**460**	**180**	0.06
S0	06 May 2009	1000	100	82	**0.10**
S0	14 Jul 2009	**7000**	**820**	**160**	**0.12**
S0	04 Aug 2009	**1300**	120	14	0.09
S6	17 Nov 2009	60	16	**400**	0.27
S0	24 Nov 2009	**1600**	**440**	80	**0.28**
S0	01 Dec 2009	**2600**	92	18	0.04
S2	01 Dec 2009	**>16,000**	**2800**	**180**	**0.18**
S3	01 Dec 2009	**>16,000**	**880**	**160**	0.06
S4	01 Dec 2009	**>16,000**	**6000**	16	**0.38**
S10	01 Dec 2009	**>16,000**	**4800**	48	**0.30**
S0	08 Dec 2009	**>16,000**	**1200**	**3600**	0.08
S2	08 Dec 2009	**>16,000**	**1800**	**>12,000**	**0.11**
S3	08 Dec 2009	**>16,000**	**1000**	**7400**	0.06
S4	08 Dec 2009	**>16,000**	**5000**	**>12,000**	**0.31**
S5	08 Dec 2009	**>16,000**	**>12,000**	**>12,000**	**0.75**
S6	08 Dec 2009	**>16,000**	**1200**	**3800**	0.08
S8	08 Dec 2009	**>16,000**	**2000**	**4200**	**0.13**
S10	08 Dec 2009	**>16,000**	**1200**	**6200**	0.08
S11	08 Dec 2009	**>16,000**	**2000**	**6400**	**0.13**
S12	08 Dec 2009	**>16,000**	**980**	**4000**	0.06
S0	15 Dec 2009	**4200**	220	**400**	0.05
S2	15 Dec 2009	**3800**	160	**260**	0.04
S3	15 Dec 2009	**11,000**	240	**660**	0.02
S4	15 Dec 2009	**>16,000**	**840**	**660**	0.05
S5	15 Dec 2009	**>16,000**	**8200**	**>12,000**	**0.51**
S10	15 Dec 2009	**>16,000**	**720**	**800**	0.05
S0	22 Dec 2009	**6800**	**560**	**440**	0.08
S3	22 Dec 2009	**8000**	120	44	0.02
S4	22 Dec 2009	**6400**	200	24	0.03
S6	22 Dec 2009	**11,000**	300	64	0.03
S8	22 Dec 2009	400	2	**1000**	0.01
S10	22 Dec 2009	**2200**	80	32	0.04
S12	22 Dec 2009	**>16,000**	**1000**	**260**	0.06
S0	29 Dec 2009	**9600**	**2800**	**1400**	**0.29**
S5	29 Dec 2009	**4800**	120	**300**	0.03

Appendix B.3

Summary of samples with elevated (bold) total coliform (>1000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), and/or enterococcus (>104 CFU/100 mL) densities collected at SBOO kelp bed stations during 2009. Bold F:T values are samples collected in 2009 which meet the FTR criteria for contamination (Total ≥1000 CFU/100 mL and F:T ≥0.10). Values are expressed as CFU/100 mL; Total = total coliform; Fecal = fecal coliform; Entero = enterococcus; F:T = fecal to total coliform ratio.

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
I25	14 Jan 2009	2	**>16,000**	**1400**	**260**	0.09
I25	14 Jan 2009	6	**>16,000**	**1200**	**340**	0.08
I25	14 Jan 2009	9	**>16,000**	**4200**	**180**	**0.26**
I39	14 Jan 2009	18	**1600**	**420**	78	**0.26**
I25	17 Feb 2009	2	**>16,000**	**5400**	**9600**	**0.34**
I25	17 Feb 2009	6	**>16,000**	**460**	**500**	0.03
I25	17 Feb 2009	9	**14,000**	340	**340**	0.02
I26	17 Feb 2009	2	**>16,000**	**4600**	**1400**	0.29
I26	17 Feb 2009	6	**5400**	280	**300**	0.05
I26	17 Feb 2009	9	**6600**	200	**240**	0.03
I25	03 Oct 2009	2	2	2	**140**	1.00
I25	13 Dec 2009	6	380	10	**140**	0.03
I25	13 Dec 2009	9	240	10	**280**	0.04
I26	13 Dec 2009	2	**4200**	66	**220**	0.02
I26	13 Dec 2009	6	280	20	**180**	0.07
I26	13 Dec 2009	9	320	14	**140**	0.04
I39	13 Dec 2009	18	180	12	**140**	0.07
I25	18 Dec 2009	6	480	16	**120**	0.03
I25	18 Dec 2009	9	420	16	**130**	0.04

Appendix B.4

Summary of samples with elevated (bold) total coliform (>1000 CFU/100 mL), fecal coliform (>400 CFU/100 mL), and/or enterococcus (>104 CFU/100 mL) densities collected at SBOO offshore stations during 2009. Bold F:T values are samples collected in 2009 which meet the FTR criteria for contamination (Total ≥1000 CFU/100 mL and F:T ≥0.10). Values are expressed as CFU/100 mL; Total=total coliform; Fecal=fecal coliform; Entero=enterococcus; F:T=fecal to total coliform ratio.

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
I12	07 Jan 2009	2	**12,000**	**1600**	**400**	**0.13**
I12	07 Jan 2009	18	**1800**	360	74	**0.20**
I14	07 Jan 2009	27	40	16	**320**	0.40
I18	07 Jan 2009	18	20	24	**240**	1.20
I19	07 Jan 2009	2	**>16,000**	**600**	**260**	0.04
I19	07 Jan 2009	6	**1600**	**620**	62	**0.39**
I19	07 Jan 2009	11	80	38	**110**	0.48
I11	08 Jan 2009	2	**3200**	**860**	80	**0.27**
I11	08 Jan 2009	6	**4400**	**540**	86	**0.12**
I11	08 Jan 2009	11	420	26	**120**	0.06
I12	02 Feb 2009	2	**12,000**	**2000**	**440**	**0.17**
I12	02 Feb 2009	18	**>16,000**	**10,000**	**2200**	**0.63**
I16	02 Feb 2009	18	**>16,000**	**5000**	**1200**	**0.31**
I33	04 Feb 2009	18	**4400**	**560**	**340**	**0.13**
I12	02 Mar 2009	18	**>16,000**	**1000**	14	0.06
I16	02 Mar 2009	18	**>16,000**	**2000**	**420**	**0.13**
I19	02 Mar 2009	2	**>16,000**	**680**	50	0.07
I40	02 Mar 2009	2	**>16,000**	**14,000**	**580**	**0.88**
I9	04 Mar 2009	18	**>16,000**	**620**	4	0.04
I9	07 Apr 2009	18	**3600**	64	**110**	0.02
I12	08 Apr 2009	18	**>16,000**	**9400**	**3000**	**0.59**
I12	08 Apr 2009	27	**5800**	**680**	**130**	**0.12**
I12	08 Jun 2009	27	**8600**	**2200**	**500**	**0.26**
I9	11 Jun 2009	18	**1800**	**520**	90	**0.29**
I14	06 Jul 2009	18	**1600**	**420**	**130**	**0.26**
I16	06 Jul 2009	18	**14,000**	**1400**	**700**	**0.10**
I12	10 Aug 2009	18	**>16,000**	**7600**	**1400**	**0.48**
I18	10 Aug 2009	12	260	50	**260**	0.19
I5	11 Aug 2009	2	**2600**	74	76	0.03
I12	16 Sep 2009	18	**2800**	**800**	**180**	**0.29**
I14	16 Sep 2009	18	**3800**	140	**180**	0.04
I16	16 Sep 2009	27	**>16,000**	**6000**	**4000**	**0.38**
I22	16 Sep 2009	18	660	96	**300**	0.15
I30	17 Sep 2009	18	580	120	**540**	0.21
I33	07 Oct 2009	18	940	220	**160**	0.23

Appendix B.4 *continued*

Station	Date	Depth (m)	Total	Fecal	Entero	F:T
I12	09 Nov 2009	18	**1500**	380	80	**0.25**
I5	10 Dec 2009	6	**1300**	24	**260**	0.02
I5	10 Dec 2009	11	1000	70	**140**	0.07
I11	10 Dec 2009	2	**1400**	100	**360**	0.07
I11	10 Dec 2009	6	1000	28	**180**	0.03
I11	10 Dec 2009	11	**9800**	260	**260**	0.03
I32	11 Dec 2009	6	500	18	**140**	0.04
I32	11 Dec 2009	9	380	24	**220**	0.06
I12	18 Dec 2009	18	**6400**	**680**	140	**0.11**
I19	18 Dec 2009	2	**2000**	68	**120**	0.03
I19	18 Dec 2009	6	800	100	**160**	0.13
I19	18 Dec 2009	11	800	54	**180**	0.07
I24	18 Dec 2009	11	**3200**	58	**300**	0.02
I40	18 Dec 2009	2	**1800**	46	**110**	0.03
I40	18 Dec 2009	6	**1600**	70	**150**	0.04
I40	18 Dec 2009	9	**4800**	130	**400**	0.03

Appendix B.5

Summary of compliance with California Ocean Plan water contact standards for SBOO shore and kelp bed stations during 2009. The values reflect the number of days that each station exceeded the 30-day total coliform, 10,000 total coliform, the 60-day fecal coliform, and 30-day fecal geometric mean standards (see Chapter 3; Box 3.1). Shore stations are listed north to south from left to right.

		Shore Stations								Kelp Bed Stations		
Month	**# Days**	**S9**	**S8**	**S12**	**S6**	**S11**	**S5**	**S10**	**S4**	**I25**	**I26**	**I39**
30-day Total Coliform Standard												
January	31	9	9	27	15	21	31	31	31	31	17	6
February	28	0	0	13	11	11	28	28	28	23	7	0
March	31	0	0	18	18	23	31	31	31	18	18	0
April	30	0	0	0	0	0	16	1	1	0	0	0
May	31	0	0	0	0	0	13	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0	0	0	0
December	31	0	23	23	23	23	23	30	30	0	0	0
Percent Compliance		**98%**	**91%**	**78%**	**82%**	**79%**	**61%**	**67%**	**67%**	**80%**	**89%**	**98%**
10,000 Total Coliform Standard												
January	31	0	0	0	0	0	2	2	0	0	0	0
February	28	0	0	1	0	0	3	1	0	0	0	0
March	31	0	0	0	0	0	1	1	1	0	0	0
April	30	0	0	0	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0	0	0	0
December	31	0	0	0	1	1	1	2	2	0	0	0
Total		**0**	**0**	**1**	**1**	**1**	**7**	**6**	**3**	**0**	**0**	**0**

Appendix B.5 *continued*

Month	# Days	Shore Stations								Kelp Bed Stations		
		S9	S8	S12	S6	S11	S5	S10	S4	I25	I26	I39
60-day Fecal Coliform Standard												
January	31	31	31	31	31	31	31	31	31	31	7	16
February	28	13	17	26	28	28	28	28	28	28	0	3
March	31	0	14	31	17	31	31	31	31	14	0	0
April	30	0	6	18	15	27	30	30	30	0	0	0
May	31	0	0	0	13	12	14	2	2	0	0	0
June	30	0	0	0	4	4	4	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0	0	0	0
December	31	0	10	17	7	10	24	31	31	0	0	0
Percent Compliance		**88%**	**79%**	**66%**	**69%**	**61%**	**56%**	**58%**	**58%**	**80%**	**98%**	**95%**
30-day Fecal Geometric Mean Standard												
January	31	0	0	0	0	0	31	31	31	0	0	0
February	28	0	0	0	0	0	28	28	26	0	0	0
March	31	0	0	0	0	0	25	12	14	0	0	0
April	30	0	0	0	0	0	0	0	0	0	0	0
May	31	0	0	0	0	0	0	0	0	0	0	0
June	30	0	0	0	0	0	0	0	0	0	0	0
July	31	0	0	0	0	0	0	0	0	0	0	0
August	31	0	0	0	0	0	0	0	0	0	0	0
September	30	0	0	0	0	0	0	0	0	0	0	0
October	31	0	0	0	0	0	0	0	0	0	0	0
November	30	0	0	0	0	0	0	0	0	0	0	0
December	31	0	0	0	0	0	8	22	22	0	0	0
Percent Compliance		**100%**	**100%**	**100%**	**100%**	**100%**	**75%**	**75%**	**75%**	**100%**	**100%**	**100%**

Appendix C

Supporting Data

2009 SBOO Stations

Sediment Characteristics

Appendix C.1

Constituents and method detection limits (MDL) for sediment samples analyzed for the SBOO monitoring program during 2009.

Parameter	MDL	Parameter	MDL
Organic Indicators			
Total Sulfides (ppm)	0.14	Total Solids (% weight)	0.24
Total Nitrogen (% weight)	0.005	Total Volatile Solids (% weight)	0.11
Total Organic Carbon (% weight)	0.01		
Metals (ppm)			
Aluminum (Al)	2	Lead (Pb)	0.8
Antimony (Sb)	0.3	Manganese (Mn)	0.08
Arsenic (As)	0.33	Mercury (Hg)	0.003
Barium (Ba)	0.02	Nickel (Ni)	0.1
Beryllium (Be)	0.01	Selenium (Se)	0.24
Cadmium (Cd)	0.06	Silver (Ag)	0.04
Chromium (Cr)	0.1	Thallium (Tl)	0.5
Copper (Cu)	0.2	Tin (Sn)	0.3
Iron (Fe)	9	Zinc (Zn)	0.2
Pesticides (ppt)			
Aldrin	700	Cis Nonachlor	700
Alpha Endosulfan	700	Gamma (trans) Chlordane	700
Beta Endosulfan	700	Gamma Chlordene	*
Dieldrin	700	Heptachlor	700
Endosulfan Sulfate	700	Heptachlor epoxide	700
Endrin	700	Methoxychlor	700
Endrin aldehyde	700	Oxychlordane	700
Hexachlorobenzene (HCB)	400	Trans Nonachlor	700
Mirex	700	o,p-DDD	400
HCH, Alpha isomer	400	o,p-DDE	700
HCH, Beta isomer	400	o,p-DDT	700
HCH, Delta isomer	400	p,p-DDMU	*
HCH, Gamma isomer	400	p,p-DDD	700
Alpha (cis) Chlordane	700	p,p-DDE	400
Alpha Chlordene	*	p,p-DDT	700

* No MDL available for this parameter.

Appendix C.1 *continued*

Parameter	MDL	Parameter	MDL
Polychlorinated Biphenyl Congeners (PCBs) (ppt)			
PCB 18	700	PCB 126	1500
PCB 28	700	PCB 128	700
PCB 37	700	PCB 138	700
PCB 44	700	PCB 149	700
PCB 49	700	PCB 151	700
PCB 52	700	PCB 153/168	700
PCB 66	700	PCB 156	700
PCB 70	700	PCB 157	700
PCB 74	700	PCB 158	700
PCB 77	700	PCB 167	700
PCB 81	700	PCB 169	700
PCB 87	700	PCB 170	700
PCB 99	700	PCB 177	700
PCB 101	700	PCB 180	400
PCB 105	700	PCB 183	700
PCB 110	700	PCB 187	700
PCB 114	700	PCB 189	400
PCB 118	700	PCB 194	700
PCB 119	700	PCB 201	700
PCB 123	700	PCB 206	700
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)			
1-methylnaphthalene	40 [a]	Benzo[K]fluoranthene	70 [a]
1-methylphenanthrene	40 [a]	Benzo[e]pyrene	73 [a]
2,3,5-trimethylnaphthalene	40 [a]	Biphenyl	40 [b]
2,6-dimethylnaphthalene	40 [a]	Chrysene	40
2-methylnaphthalene	40 [a]	Dibenzo(A,H)anthracene	50 [a]
3,4-benzo(B)fluoranthene	51 [a]	Fluoranthene	40 [a]
Acenaphthene	40 [a]	Fluorene	40 [a]
Acenaphthylene	40 [b]	Indeno(1,2,3-CD)pyrene	67 [a]
Anthracene	40 [a]	Naphthalene	40 [b]
Benzo[A]anthracene	40 [a]	Perylene	40 [b]
Benzo[A]pyrene	40 [a]	Phenanthrene	40 [b]
Benzo[G,H,I]perylene	66 [a]	Pyrene	40 [a]

[a] 20 for most July survey samples
[b] 30 for most July survey samples

Appendix C.2

Summary of the constituents that make up total DDT and total PCB in each sediment sample collected as part of the SBOO monitoring program during 2009; nd = not detected.

Station	Class	Constituent	January	July	Units
I1	PCB	PCB 206	500	nd	ppt
I2	PCB	PCB 206	490	nd	ppt
I3	PCB	PCB 206	360	nd	ppt
I4	PCB	PCB 206	670	nd	ppt
I7	PCB	PCB 206	450	nd	ppt
I9	DDT	p,p-DDE	220	95	ppt
I9	PCB	PCB 206	520	nd	ppt
I10	DDT	p,p-DDE	nd	95	ppt
I10	PCB	PCB 206	970	nd	ppt
I12	DDT	p,p-DDE	220	nd	ppt
I12	PCB	PCB 206	710	nd	ppt
I13	PCB	PCB 206	400	nd	ppt
I14	DDT	p,p-DDE	420	240	ppt
I14	PCB	PCB 206	360	nd	ppt
I15	PCB	PCB 206	580	nd	ppt
I16	DDT	o,p-DDD	300	nd	ppt
I16	DDT	p,p-DDE	7300	160	ppt
I16	DDT	p,p-DDT	1800	nd	ppt
I16	PCB	PCB 49	590	nd	ppt
I16	PCB	PCB 153/168	250	nd	ppt
I18	DDT	p,p-DDE	590	nd	ppt
I20	PCB	PCB 206	380	nd	ppt
I21	PCB	PCB 206	670	nd	ppt
I22	DDT	p,p-DDE	400	200	ppt
I22	PCB	PCB 206	330	nd	ppt
I23	DDT	p,p-DDE	370	nd	ppt
I23	PCB	PCB 206	650	nd	ppt
I27	DDT	p,p-DDE	380	270	ppt
I27	PCB	PCB 206	510	nd	ppt

Appendix C.2 *continued*

Station	Class	Constituent	January	July	Units
I28	DDT	o,p-DDD	nd	85	ppt
I28	DDT	p,p-DDD	nd	150	ppt
I28	DDT	p,p-DDE	380	640	ppt
I28	DDT	p,p-DDT	nd	190	ppt
I28	PCB	PCB 153/168	nd	33	ppt
I28	PCB	PCB 206	510	nd	ppt
I29	DDT	o,p-DDD	nd	210	ppt
I29	DDT	o,p-DDT	nd	390	ppt
I29	DDT	p,p-DDD	320	570	ppt
I29	DDT	p,p-DDE	1600	3100	ppt
I29	DDT	p,p-DDT	790	1400	ppt
I29	PCB	PCB 206	580	nd	ppt
I30	DDT	p,p-DDE	370	200	ppt
I30	PCB	PCB 206	540	nd	ppt
I31	DDT	p,p-DDE	190	nd	ppt
I31	PCB	PCB 206	620	nd	ppt
I34	PCB	PCB 206	340	nd	ppt
I35	DDT	p,p-DDE	nd	210	ppt
I35	PCB	PCB 206	550	nd	ppt

Appendix C.3

SBOO sediment statistics for the January 2009 survey. Stations nearest the outfall are in bold.

	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skewness (phi)	Kurtosis (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
19-m Stations												
I35	0.08	3.7	1.16	3.5	0.3	1.2	0.0	67.0	31.8	1.2	33.0	Silt, some organic debris
I34	0.27	1.9	0.74	2.0	-0.2	0.9	0.9	98.6	0.5	0.0	0.5	Sand, shell hash
I31	0.12	3.1	0.52	3.0	0.3	3.2	0.0	92.0	8.0	0.1	8.0	Silt
I23	0.50	1.0	1.70	1.0	0.0	0.9	27.1	60.2	12.7	0.0	12.7	Gravel, sand, silt, shell hash
I18	0.05	4.4	1.86	3.4	0.8	0.7	0.0	56.3	36.5	7.2	43.7	Fine sand with silt
I10	0.12	3.1	0.61	3.0	0.3	2.8	0.0	90.9	8.9	0.1	9.1	Fine sand, some organic debris
I4	0.43	1.2	0.85	1.2	0.1	1.0	5.8	93.9	0.3	0.0	0.3	Sand with fine sand, shell hash
28-m Stations												
I33	0.12	3.1	0.90	3.0	0.5	6.1	0.0	86.4	13.0	0.6	13.6	Silt
I30	0.10	3.4	0.92	3.3	0.2	1.7	0.0	83.0	16.2	0.8	17.0	Silt
I27	0.10	3.3	0.73	3.3	0.2	1.4	0.0	87.0	12.7	0.2	12.9	Silt
I22	0.11	3.1	0.90	3.0	0.3	2.0	0.0	86.6	13.0	0.4	13.4	Fine sand, silt, some organic debris
I14	**0.10**	**3.3**	**1.02**	**3.1**	**0.5**	**2.1**	**0.0**	**81.3**	**17.7**	**1.1**	**18.7**	**Silt with fine sand, some organic debris**
I16	**0.02**	**5.7**	**1.90**	**5.9**	**-0.2**	**1.1**	**0.0**	**20.5**	**68.3**	**11.2**	**79.5**	**Silt, some organic debris**
I15	**0.42**	**1.2**	**0.94**	**1.2**	**0.1**	**1.1**	**5.8**	**91.0**	**3.2**	**0.0**	**3.2**	**Sand**
I12	**0.12**	**3.1**	**0.83**	**3.0**	**0.2**	**1.8**	**0.0**	**88.3**	**11.4**	**0.3**	**11.7**	**Fine sand with silt, some organic debris**
I9	0.10	3.4	0.78	3.3	0.2	1.4	0.0	83.2	16.4	0.4	16.8	Fine sand and silt, some organic debris
I6	0.53	0.9	0.72	0.9	0.1	1.0	8.6	91.3	0.0	0.0	0.0	Red relict sand, shell hash
I3	0.46	1.1	0.81	1.1	0.1	0.9	7.1	92.9	0.0	0.0	0.0	Sand with red relict sand, shell hash
I2	0.35	1.5	0.84	1.6	-0.1	0.9	4.8	94.7	0.5	0.0	0.5	Fine sand
38-m Stations												
I29	0.09	3.5	1.17	3.3	0.4	1.4	0.0	73.5	25.4	1.1	26.5	Silt, coarse sand, shell hash, organic debris
I21	0.47	1.1	0.67	1.0	0.2	2.1	7.0	92.5	0.5	0.0	0.5	Red relict sand
I13	0.60	0.7	0.61	0.7	0.2	1.1	9.2	90.8	0.0	0.0	0.0	Red relict sand, shell hash
I8	0.47	1.1	0.84	1.1	0.1	0.8	7.2	90.4	2.3	0.0	2.3	Sand
55-m Stations												
I28	0.05	4.2	1.87	3.8	0.3	1.1	4.3	53.6	38.2	3.8	42.0	Silt and coarse black sand
I20	0.59	0.8	0.98	0.6	0.4	1.9	14.9	80.4	4.6	0.1	4.7	Red relict sand, shell hash
I7	0.57	0.8	0.79	0.7	0.2	1.2	12.0	86.6	1.4	0.0	1.4	Red relict sand
I1	0.13	2.9	0.97	2.8	0.4	2.0	0.0	89.9	9.7	0.4	10.1	Fine sand
January Max	0.60	5.7	1.90	5.9	0.8	6.1	27.1	98.6	68.3	11.2	79.5	
Pre-discharge Max	0.76	4.2	2.50	3.9	0.8	7.4	52.5	100.0	44.0	5.3	47.2	

Appendix C.3 *continued*

SBOO sediment statistics for the July 2009 survey. Stations nearest the outfall are in bold.

	Mean (mm)	Mean (phi)	SD (phi)	Median (phi)	Skewness (phi)	Kurtosis (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
19-m Stations												
I35	0.08	3.7	1.16	3.5	0.3	1.2	0.0	67.1	31.7	1.2	32.9	Silt, organic material, shell hash
I34	0.23	2.1	0.58	2.1	-0.2	2.0	3.9	94.5	1.6	0.0	1.6	Red relict sand, shell hash
I31	0.12	3.1	0.55	3.0	0.3	2.9	0.0	91.3	8.6	0.1	8.7	Silt, some organic debris
I23	0.12	3.1	0.71	3.0	0.5	5.3	0.0	89.0	10.7	0.3	11.0	Fine sand, silt, shell hash, some organic debris
I18	0.11	3.2	0.74	3.1	0.2	1.3	0.0	89.1	10.6	0.2	10.9	Fine sand with silt, some organic debris, shell hash
I10	0.12	3.1	0.72	3.1	0.2	1.3	0.0	91.1	8.7	0.1	8.8	Fine sand, silt, some organic material, sand tubes
I4	0.66	0.6	0.69	0.5	0.4	1.3	11.8	87.8	0.4	0.0	0.4	Sand, fine sand, shell hash, pea gravel
28-m Stations												
I33	0.12	3.1	0.89	3.0	0.4	6.2	0.0	87.1	12.3	0.5	12.9	Fine sand and silt, organic material, shell hash
I30	0.10	3.4	0.87	3.3	0.2	1.7	0.0	83.8	15.6	0.6	16.2	Silt, some organic debris
I27	0.10	3.3	0.89	3.3	0.2	1.7	0.0	83.9	15.4	0.6	16.1	Silt, some organic debris
I22	0.11	3.1	0.89	3.1	0.3	1.9	0.0	86.7	12.9	0.4	13.3	Fine sand with silt, some organic material
I14	**0.10**	**3.3**	**0.85**	**3.2**	**0.3**	**1.7**	**0.0**	**85.3**	**14.2**	**0.5**	**14.7**	**Fine sand with silt, some organic material**
I16	**0.22**	**2.2**	**1.27**	**2.4**	**-0.1**	**1.1**	**2.1**	**90.2**	**7.6**	**0.1**	**7.7**	**Fine sand with silt, some organic material**
I15	**0.23**	**2.1**	**0.90**	**2.1**	**0.1**	**1.4**	**0.0**	**94.2**	**5.8**	**0.0**	**5.8**	**Fine sand, silt, organic material, sand tubes**
I12	**0.13**	**3.0**	**0.91**	**2.9**	**0.2**	**1.8**	**0.0**	**88.9**	**10.8**	**0.3**	**11.1**	**Fine sand, silt, organic material, shell hash**
I9	0.10	3.3	0.83	3.3	0.2	1.5	0.0	83.4	16.1	0.5	16.6	Silt and fine sand, some organic material
I6	0.49	1.0	0.79	0.9	0.2	1.0	7.8	91.8	0.3	0.0	0.3	Red relict sand, shell hash
I3	0.52	1.0	0.75	0.9	0.2	1.0	8.8	90.0	1.2	0.0	1.2	Sand with fine sand
I2	0.37	1.5	0.87	1.3	0.2	0.9	5.2	93.4	1.4	0.0	1.4	Sand with fine sand
38-m Stations												
I29	0.07	3.9	1.49	3.6	0.3	1.2	0.0	62.0	35.8	2.2	38.0	Red relict sand, fine sand, silt, gravel
I21	0.56	0.8	0.69	0.8	0.2	1.0	9.2	90.8	0.0	0.0	0.0	Fine red relict sand, shell hash
I13	0.51	1.0	0.88	0.8	0.3	0.9	7.2	89.2	3.6	0.0	3.6	Red relict sand, shell hash
I8	0.36	1.5	1.04	1.4	0.1	1.1	5.5	90.3	4.2	0.0	4.2	Fine sand and sand
55-m Stations												
I28	0.28	1.9	1.78	1.5	0.2	0.7	15.4	64.0	20.6	0.0	20.6	Coarse dark sand, silt, shell hash
I20	0.58	0.8	0.74	0.7	0.2	1.1	12.2	87.3	0.5	0.0	0.5	Red relict sand, shell hash
I7	0.57	0.8	1.10	0.5	0.6	1.4	12.0	82.9	5.0	0.1	5.1	Red relict sand, coarse sand, shell hash
I1	0.12	3.0	1.00	3.0	0.3	2.7	0.0	89.0	10.6	0.4	11.0	Fine sand and silt
July Max	0.66	3.9	1.78	3.6	0.6	6.2	15.4	94.5	35.8	2.2	38.0	
Pre-discharge Max	0.76	4.2	2.50	3.9	0.8	7.4	52.5	100.0	44.0	5.3	47.2	

Appendix C.4

Summary of organic loading indicators at SBOO benthic stations for the January (A) and July (B) 2009 surveys. Stations nearest the outfall are in bold; TN = total nitrogen; TOC = total organic carbon; nd = not detected.

A	Sulfides (ppm)	TN (% wt)	TOC (% wt)	B	Sulfides (ppm)	TN (% wt)	TOC (% wt)
19-m Stations				*19-m Stations*			
I35	1.56	0.036	0.327	I35	24.60	0.038	0.363
I34	0.94	nd	0.187	I34	0.85	0.012	0.256
I31	0.21	0.017	0.106	I31	0.51	0.026	0.115
I23	1.04	0.037	5.460	I23	0.42	0.019	0.185
I18	1.46	0.024	0.269	I18	1.35	0.020	0.147
I10	nd	0.015	0.128	I10	1.09	0.020	0.148
I4	0.19	0.010	0.213	I4	nd	0.015	0.152
28-m Stations				*28-m Stations*			
I33	1.49	0.030	0.618	I33	1.56	0.025	0.395
I30	1.05	0.027	0.235	I30	1.44	0.031	0.263
I27	2.34	0.022	0.182	I27	2.52	0.026	0.219
I22	0.77	0.019	0.218	I22	1.70	0.030	0.243
I14	**0.89**	**0.027**	**0.261**	**I14**	**1.48**	**0.028**	**0.232**
I16	**25.30**	**0.163**	**2.120**	**I16**	**nd**	**0.019**	**0.122**
I15	**0.59**	**0.012**	**0.052**	**I15**	**0.63**	**0.019**	**0.107**
I12	**8.32**	**0.018**	**0.161**	**I12**	**1.47**	**0.016**	**0.145**
I9	1.44	0.021	0.203	I9	0.89	0.026	0.236
I6	0.30	0.010	0.050	I6	nd	0.015	0.055
I3	0.32	0.011	0.030	I3	1.39	0.015	0.067
I2	0.25	0.011	0.043	I2	0.39	0.017	0.085
38-m Stations				*38-m Stations*			
I29	1.61	0.027	0.628	I29	6.07	0.087	1.030
I21	0.15	0.011	0.042	I21	0.99	0.013	0.074
I13	0.50	0.010	0.050	I13	nd	0.015	0.116
I8	0.28	0.010	0.040	I8	0.27	0.019	0.100
55-m Stations				*55-m Stations*			
I28	0.49	0.043	0.737	I28	0.68	0.030	0.552
I20	0.18	0.011	0.049	I20	0.17	0.012	0.049
I7	nd	0.008	0.032	I7	0.52	0.020	0.194
I1	1.32	0.023	0.292	I1	0.53	0.024	0.296
Detection Rate (%)	93	96	100	Detection Rate (%)	85	100	100

Appendix C.5

Concentrations of trace metals (ppm) for the January 2009 survey. Stations nearest the outfall are in bold; ERL=effects range low threshold value; ERM=effects range median threshold value; na=not available; nd=not detected. See Appendix C.1 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																		
I35	7960	0.4	1.25	41.90	nd	0.10	13.2	4.5	9360	3.21	95.4	0.018	4.6	nd	nd	nd	0.45	28.10
I34	1520	nd	1.28	5.66	nd	nd	3.5	0.8	2710	1.48	23.8	0.003	0.7	nd	nd	nd	nd	5.51
I31	4010	nd	0.69	17.90	nd	nd	7.6	1.2	3820	1.07	49.4	nd	1.7	nd	nd	nd	nd	9.80
I23	5520	0.4	2.60	29.70	nd	0.11	9.4	5.8	6530	3.20	59.2	0.006	3.7	nd	nd	nd	0.88	21.10
I18	7540	nd	1.57	59.50	nd	0.09	13.4	5.6	8590	3.68	81.6	0.004	4.8	nd	nd	nd	1.02	28.20
I10	6090	0.4	1.67	35.70	nd	nd	10.9	2.6	6890	1.80	70.7	nd	3.3	nd	nd	nd	0.94	20.60
I4	1010	nd	1.73	3.77	nd	nd	5.0	1.4	1740	1.27	9.2	nd	0.8	nd	0.36	nd	0.60	8.09
28-m Stations																		
I33	5460	nd	0.36	23.50	nd	0.06	9.1	3.9	6390	2.86	71.5	0.016	17.6	nd	nd	nd	0.46	18.30
I30	7030	0.3	1.84	35.00	nd	0.07	12.1	3.9	7280	1.91	71.6	0.006	4.0	nd	nd	nd	nd	20.60
I27	7860	0.4	1.15	37.60	nd	0.07	12.1	3.8	7010	1.99	73.9	0.004	3.9	nd	nd	nd	0.88	24.50
I22	5660	0.4	1.31	32.00	nd	0.06	10.8	2.9	5790	2.05	59.5	0.004	3.6	nd	nd	nd	1.00	19.70
I14	**4430**	**0.4**	**1.79**	**46.00**	**nd**	**0.07**	**12.2**	**4.9**	**5670**	**2.68**	**79.5**	**0.005**	**4.4**	**nd**	**nd**	**nd**	**0.73**	**25.80**
I16	**30100**	**0.9**	**9.18**	**177.00**	**nd**	**0.42**	**33.2**	**37.6**	**29300**	**20.00**	**291.0**	**0.063**	**22.8**	**nd**	**nd**	**nd**	**4.50**	**126.00**
I15	**1580**	**nd**	**1.98**	**6.05**	**nd**	**nd**	**8.4**	**0.9**	**4070**	**1.92**	**19.7**	**nd**	**1.1**	**nd**	**0.63**	**nd**	**0.58**	**10.80**
I12	**8280**	**0.3**	**1.47**	**53.60**	**nd**	**nd**	**12.9**	**3.9**	**9050**	**1.88**	**95.3**	**0.003**	**4.3**	**nd**	**nd**	**nd**	**0.78**	**29.30**
I9	8500	0.4	2.26	46.00	nd	0.07	13.3	5.9	8630	1.63	86.4	0.004	5.1	nd	nd	nd	0.66	27.60
I6	1160	0.3	5.85	4.04	nd	nd	9.4	1.9	4400	1.83	10.7	nd	0.9	nd	0.45	nd	0.57	7.87
I3	741	nd	1.32	2.80	nd	nd	6.5	1.5	1400	1.05	5.7	nd	0.8	nd	0.24	nd	1.04	3.92
I2	1020	nd	0.89	3.74	nd	nd	6.1	1.6	1300	0.93	8.7	nd	0.8	nd	0.30	nd	0.76	5.89
38-m Stations																		
I29	6770	nd	1.89	33.20	nd	0.08	12.2	3.7	7970	2.62	68.9	0.010	4.5	nd	nd	nd	0.40	20.10
I21	1260	0.3	11.90	3.93	nd	0.07	13.2	2.0	8550	3.90	16.7	nd	1.2	nd	0.45	nd	0.59	14.90
I13	1190	0.3	6.01	3.73	nd	nd	10.6	0.3	6060	2.82	17.0	nd	0.9	nd	0.48	nd	0.54	9.56
I8	1470	nd	1.58	4.12	nd	nd	7.9	1.9	3660	1.36	16.9	nd	1.0	nd	0.57	nd	0.65	10.70
55-m Stations																		
I28	5150	nd	2.24	25.20	nd	0.09	9.8	4.4	7080	3.12	56.4	0.019	5.1	nd	nd	nd	0.46	18.80
I20	1600	0.3	3.32	4.77	nd	nd	6.8	5.6	5710	2.22	19.9	nd	1.2	nd	0.48	nd	0.81	12.60
I7	1260	nd	6.47	4.04	nd	nd	8.9	0.7	6690	2.50	17.1	nd	1.0	nd	0.35	nd	0.67	9.61
I1	2470	nd	1.29	12.50	nd	0.10	8.0	3.2	3670	2.00	33.7	0.005	3.0	nd	0.53	nd	0.67	11.30
Detection Rate (%)	100	52	100	100	0	52	100	100	100	100	100	56	100	0	41	0	89	100
ERL	na	na	8.2	na	na	1.2	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

Appendix C.5 *continued*

Concentrations of trace metals (ppm) for the July 2009 survey. Stations nearest the outfall are in bold; ERL=effects range low threshold value; ERM=effects range median threshold value; na=not available; nd=not detected. See Appendix C.1 for MDLs and names for each metal represented by periodic table symbol.

	Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
19-m Stations																		
I35	9030	nd	2.09	42.30	0.18	0.12	13.9	4.5	10900	3.12	108.0	0.021	7.2	nd	nd	nd	0.72	28.60
I34	1900	nd	1.60	6.62	0.02	nd	3.2	1.2	2870	1.37	21.9	0.003	0.8	nd	nd	nd	0.32	5.69
I31	4080	nd	1.29	15.30	0.05	nd	6.4	1.5	3550	0.95	33.6	nd	1.6	nd	nd	nd	nd	8.56
I23	5380	nd	1.61	33.00	0.08	0.06	7.7	2.1	5260	1.33	47.3	0.004	2.6	nd	nd	nd	0.33	12.60
I18	5830	nd	1.68	40.50	0.08	nd	9.7	3.8	6530	1.31	57.5	nd	2.6	nd	nd	nd	nd	13.90
I10	5290	nd	1.81	31.60	0.08	nd	8.1	2.7	5990	1.25	55.6	nd	2.7	nd	nd	nd	0.35	14.70
I4	1030	nd	1.06	3.36	nd	nd	3.8	0.6	1830	0.97	12.6	0.005	1.0	nd	nd	nd	nd	3.37
28-m Stations																		
I33	5420	nd	1.63	23.50	0.08	0.08	8.1	3.4	6190	2.48	61.8	0.012	2.7	nd	nd	nd	0.56	17.10
I30	7920	nd	1.92	30.20	0.11	0.08	10.5	3.3	7080	1.37	60.8	0.005	3.6	nd	nd	nd	0.43	18.00
I27	6770	nd	2.01	29.90	0.10	nd	9.5	1.7	6670	1.34	57.4	nd	3.4	nd	nd	nd	0.36	16.50
I22	6230	nd	1.67	27.80	0.09	0.08	9.0	3.0	5960	1.51	52.4	0.004	3.2	nd	nd	nd	0.41	14.40
I14	**7760**	**0.4**	**2.21**	**40.30**	**0.12**	**0.07**	**19.5**	**3.9**	**8090**	**1.47**	**71.3**	**0.004**	**5.8**	**nd**	**nd**	**nd**	**0.41**	**22.50**
I16	**4280**	**nd**	**1.84**	**17.70**	**0.07**	**nd**	**7.4**	**3.3**	**4880**	**1.28**	**42.4**	**0.004**	**2.0**	**nd**	**nd**	**nd**	**nd**	**12.30**
I15	**3410**	**nd**	**2.01**	**9.89**	**0.06**	**nd**	**8.8**	**3.4**	**4990**	**1.74**	**33.0**	**nd**	**1.8**	**nd**	**nd**	**nd**	**0.33**	**10.60**
I12	**7040**	**nd**	**1.93**	**40.10**	**0.11**	**0.07**	**10.4**	**3.4**	**8290**	**1.21**	**71.0**	**nd**	**3.4**	**nd**	**nd**	**nd**	**0.31**	**21.10**
I9	8980	0.3	1.57	38.90	0.13	0.07	11.3	4.7	8390	0.96	73.9	0.004	4.5	nd	nd	nd	0.38	22.30
I6	1410	nd	5.93	3.13	0.02	nd	8.4	nd	4420	1.63	15.0	nd	0.8	nd	nd	nd	nd	4.38
I3	945	nd	1.04	1.99	nd	nd	5.4	0.4	1550	nd	8.0	nd	0.8	nd	nd	nd	nd	2.31
I2	1480	nd	0.66	2.74	nd	nd	5.8	0.5	1500	nd	13.3	nd	0.9	nd	nd	nd	0.35	3.15
38-m Stations																		
I29	18100	0.7	4.43	113.00	0.33	0.16	25.8	12.2	21800	4.82	188.0	0.027	12.5	nd	nd	nd	1.01	59.60
I21	1280	nd	11.30	2.32	0.05	0.08	12.5	nd	9260	3.47	13.5	nd	0.9	nd	nd	nd	nd	6.69
I13	1460	nd	7.30	2.52	0.03	nd	9.7	0.3	6140	2.65	17.0	nd	0.8	nd	nd	nd	nd	6.45
I8	1820	nd	2.57	5.10	0.04	nd	9.2	0.6	4380	1.40	18.0	nd	1.2	nd	0.10	nd	nd	7.32
55-m Stations																		
I28	6260	nd	2.81	24.30	0.12	0.08	9.0	5.8	7400	2.44	50.3	nd	4.9	nd	nd	nd	0.55	17.60
I20	1500	nd	3.13	3.54	0.04	nd	5.5	3.1	5270	1.74	15.1	nd	0.8	nd	nd	nd	nd	6.91
I7	1880	nd	5.76	4.53	0.04	nd	9.4	0.2	7460	2.50	28.5	nd	1.4	nd	nd	nd	0.42	7.79
I1	3180	nd	1.10	12.20	0.05	0.07	7.4	1.4	3970	1.55	37.6	0.006	3.0	nd	nd	nd	0.41	8.87
Detection Rate (%)	100	11	100	100	89	44	100	93	100	93	100	44	100	0	4	0	63	100
ERL	na	na	8.2	na	na	1.20	81	34	na	46.7	na	0.15	20.9	na	1	na	na	150
ERM	na	na	70	na	na	9.6	370	270	na	218	na	0.71	51.6	na	3.7	na	na	410

Appendix C.6

Concentrations of total DDT (tDDT), hexachlorobenzene (HCB), and total PCB (tPCB) detected at each SBOO benthic station during the January (A) and July (B) 2009 surveys. Stations nearest the outfall are in bold; ERL = effects range low threshold value; ERM = effects range median threshold value; na = not available; nd = not detected.

A	tDDT (ppt)	HCB (ppt)	tPCB (ppt)	B	tDDT (ppt)	HCB (ppt)	tPCB (ppt)
19-m Stations				*19-m Stations*			
I35	nd	nd	550	I35	210	nd	nd
I34	nd	nd	340	I34	nd	nd	nd
I31	190	nd	620	I31	nd	nd	nd
I23	370	130	650	I23	nd	nd	nd
I18	590	99	nd	I18	nd	nd	nd
I10	nd	100	970	I10	95	nd	nd
I4	nd	nd	670	I4	nd	nd	nd
28-m Stations				*28-m Stations*			
I33	nd	nd	nd	I33	nd	150	nd
I30	370	nd	540	I30	200	nd	nd
I27	380	nd	510	I27	270	490	nd
I22	400	130	330	I22	200	nd	nd
I14	**420**	**nd**	**360**	**I14**	**240**	**nd**	**nd**
I16	**9400**	**380**	**840**	**I16**	**160**	**nd**	**nd**
I15	**nd**	**nd**	**580**	**I15**	**nd**	**160**	**nd**
I12	**220**	**180**	**710**	**I12**	**nd**	**nd**	**nd**
I9	220	nd	520	I9	95	nd	nd
I6	nd	nd	nd	I6	nd	nd	nd
I3	nd	nd	360	I3	nd	nd	nd
I2	nd	nd	490	I2	nd	nd	nd
38-m Stations				*38-m Stations*			
I29	2710	77	580	I29	5670	620	nd
I21	nd	nd	670	I21	nd	700	nd
I13	nd	nd	400	I13	nd	nd	nd
I8	nd	nd	nd	I8	nd	nd	nd
55-m Stations				*55-m Stations*			
I28	380	nd	510	I28	1065	180	33
I20	nd	nd	380	I20	nd	nd	nd
I7	nd	nd	450	I7	nd	nd	nd
I1	nd	nd	500	I1	nd	nd	nd
Detection Rate (%)	44	26	85	Detection Rate (%)	37	22	4
ERL	1580	na	na	ERL	1580	na	na
ERM	46100	na	na	ERM	46100	na	na

Appendix D

Supporting Data

2009 SBOO Stations

Macrobenthic Communities

Appendix D.1

All taxa composing cluster groups A–G from the 2009 surveys of SBOO benthic stations. Data are expressed as mean abundance per sample (no./0.1 m^2) for each group. Number of station/survey entities per cluster group shown in parentheses.

		Cluster Group						
Species/Taxa	Phyla	A (1)	B (2)	C (12)	D (8)	E (4)	F (7)	G (20)
Acanthoptilum sp	Cnidaria					0.1		
Acidostoma hancocki	Arthropoda			0.1	0.1			0.1
Acteocina cerealis	Mollusca				0.1	0.4		0.1
Acteocina culcitella	Mollusca			0.2			2.0	0.5
Acteocina harpa	Mollusca				0.1			0.1
Acteocina sp	Mollusca						0.1	<0.1
Actiniaria	Cnidaria		0.3	0.1	0.3	0.1	0.2	0.1
Adontorhina cyclia	Mollusca					0.1		
Aegires albopunctatus	Mollusca							<0.1
Aglaja ocelligera	Mollusca							0.1
Aglaophamus verrilli	Annelida					0.1		
Agnezia septentrionalis	Chordata			0.3	0.7	0.1		0.2
Alienacanthomysis macropsis	Arthropoda						0.1	
Alvania compacta	Mollusca			<0.1		0.1	0.4	
Alvania rosana	Mollusca							<0.1
Amaeana occidentalis	Annelida					0.5	0.1	0.2
Americhelidium shoemakeri	Arthropoda			0.8	0.1		0.1	0.1
Americhelidium sp	Arthropoda			<0.1				
Americhelidium sp SD1	Arthropoda			0.5	0.3		0.1	<0.1
Americhelidium sp SD4	Arthropoda						0.1	<0.1
Ampelisca agassizi	Arthropoda		1.0	0.1		1.5		3.0
Ampelisca brachycladus	Arthropoda		0.3	0.2			2.4	0.2
Ampelisca brevisimulata	Arthropoda			0.2		1.0	0.8	8.2
Ampelisca careyi	Arthropoda			<0.1		2.4		1.8
Ampelisca cf *brevisimulata*	Arthropoda					0.1		
Ampelisca cristata cristata	Arthropoda		0.3	4.8	6.9	0.4	8.7	1.6
Ampelisca cristata microdentata	Arthropoda			0.1			0.1	5.5
Ampelisca hancocki	Arthropoda					0.1		
Ampelisca indentata	Arthropoda					3.1		
Ampelisca lobata	Arthropoda						0.1	
Ampelisca milleri	Arthropoda							0.1
Ampelisca pacifica	Arthropoda					0.4		
Ampelisca pugetica	Arthropoda			0.1		0.4		4.6
Ampelisca sp	Arthropoda			0.1	0.1	0.1	0.1	0.4
Ampelisciphotis podophthalma	Arthropoda			0.2				0.9
Ampharete acutifrons	Annelida				0.1	0.1		
Ampharete finmarchica	Annelida							<0.1
Ampharete labrops	Annelida		0.5	0.8	0.1		4.2	2.0
Ampharete sp	Annelida				0.1	0.1	0.1	0.1
Ampharetidae	Annelida				0.1	0.6	0.1	0.1
Ampharetidae sp SD1	Annelida				0.1	0.4		
Amphicteis scaphobranchiata	Annelida			<0.1	0.1	0.5	0.3	0.7
Amphideutopus oculatus	Arthropoda			0.3		0.4		2.6
Amphiodia digitata	Echinodermata			0.1		1.9	1.6	0.9
Amphiodia psara	Echinodermata	0.5		0.1	0.3	0.1		

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Amphiodia sp	Echinodermata	1.5	0.3	0.7	1.2	3.0	1.1	1.1
Amphiodia urtica	Echinodermata		0.3	1.6	0.1	5.0		0.3
Amphioplus sp	Echinodermata			0.1		0.6		1.0
Amphioplus sp A	Echinodermata			<0.1		1.1		1.5
Amphipholis squamata	Echinodermata			0.1	0.2	0.3	0.1	0.2
Amphiporidae	Nemertea			0.2			0.2	0.3
Amphissa undata	Mollusca					1.0		0.1
Amphiura arcystata	Echinodermata					0.3		<0.1
Amphiuridae	Echinodermata			4.0	0.7	1.3	1.4	2.7
Anchicolurus occidentalis	Arthropoda		0.3	0.5			0.2	
Ancistrosyllis groenlandica	Annelida				0.1			0.1
Ancistrosyllis hamata	Annelida			<0.1				<0.1
Ancistrosyllis sp	Annelida							<0.1
Anemonactis sp	Cnidaria			<0.1	0.1		0.1	<0.1
Anobothrus gracilis	Annelida					1.9		0.1
Anoplodactylus erectus	Arthropoda			0.3	0.2	0.9		0.1
Anotomastus gordiodes	Annelida							0.3
Aonides sp SD1	Annelida		0.8	0.1	0.1			
Aoroides exilis	Arthropoda			<0.1				
Aoroides inermis	Arthropoda			0.1				
Aoroides sp	Arthropoda					0.1	0.2	0.1
Aoroides sp A	Arthropoda							<0.1
Aoroides spinosa	Arthropoda							<0.1
Aphelochaeta glandaria complex	Annelida			1.0	0.1	0.6		0.2
Aphelochaeta monilaris	Annelida					3.5	0.1	0.1
Aphelochaeta petersenae	Annelida					0.1		0.1
Aphelochaeta phillipsi	Annelida				0.2			
Aphelochaeta sp	Annelida		0.3	0.2		0.5		0.1
Aphelochaeta sp LA1	Annelida			<0.1		1.3		<0.1
Aphelochaeta sp SD5	Annelida			1.4	0.8			0.1
Aphelochaeta tigrina	Annelida					0.4		
Aphelochaeta williamsae	Annelida					0.5		
Aphrodita sp	Annelida			<0.1		0.3	0.1	0.3
Apionsoma misakianum	Sipuncula		1.0	<0.1	0.2	0.9		0.1
Apistobranchus ornatus	Annelida							0.2
Apoprionospio pygmaea	Annelida		1.5	2.4			5.5	1.4
Arachnanthus sp A	Cnidaria				0.1			
Araphura breviaria	Arthropoda					0.4		
Araphura sp SD1	Arthropoda					0.8		
Argissa hamatipes	Arthropoda			0.1	0.2	0.1	0.3	0.2
Aricidea (*Acmira*) *catherinae*	Annelida			0.1	0.1	0.3		1.3
Aricidea (*Acmira*) *cerrutii*	Annelida		0.3	1.0	0.5			
Aricidea (*Acmira*) *horikoshii*	Annelida							0.1
Aricidea (*Acmira*) *lopezi*	Annelida					0.5		0.1
Aricidea (*Acmira*) *simplex*	Annelida			<0.1	0.3	4.9		0.2
Aricidea (*Acmira*) sp	Annelida			<0.1				
Aricidea (*Acmira*) sp SD1	Annelida			<0.1		0.1		
Aricidea (*Allia*) *antennata*	Annelida							<0.1
Aricidea (*Allia*) *hartleyi*	Annelida					0.1		<0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Aricidea (*Allia*) sp A	Annelida					0.3		
Aricidea (*Allia*) sp SD1	Annelida			0.2	0.1			
Aricidea (*Aricidea*) *pseudoarticulata*	Annelida					0.1		
Aricidea (*Aricidea*) sp SD3	Annelida			0.1		0.1		
Aricidea (*Aricidea*) *wassi*	Annelida			<0.1			0.1	0.5
Armandia brevis	Annelida			0.1			0.1	0.1
Armina californica	Mollusca			<0.1				<0.1
Artacamella hancocki	Annelida				0.2	1.0		0.1
Aruga holmesi	Arthropoda							<0.1
Aruga oculata	Arthropoda		0.3	0.3	0.1	0.8		0.7
Asabellides lineata	Annelida				0.1	0.9		<0.1
Ascidiacea	Chordata			0.2	0.2	0.1		0.1
Asteroidea	Echinodermata				0.4	0.4		
Astropecten sp	Echinodermata			<0.1	0.1			
Astropecten verrilli	Echinodermata			0.3	0.3	0.3		<0.1
Astyris aurantiaca	Mollusca			0.4			0.1	
Autolytus sp	Annelida					0.3		0.3
Axinopsida serricata	Mollusca					9.1		0.4
Axiothella sp	Annelida		0.3	6.7	1.2		1.7	2.0
Balanoglossus sp	Chordata			0.2				0.1
Balcis micans	Mollusca			0.1	0.1			0.1
Balcis oldroydae	Mollusca	0.5		0.2			0.1	0.1
Bathyleberis cf *garthi*	Arthropoda			<0.1				
Bemlos audbettius	Arthropoda							<0.1
Bemlos concavus	Arthropoda							0.1
Bemlos sp	Arthropoda						0.1	<0.1
Bispira sp	Annelida					0.1	0.4	
Bivalvia	Mollusca			<0.1	0.3	0.3	0.1	0.2
Brada pluribranchiata	Annelida							0.1
Brada villosa	Annelida							0.1
Branchiostoma californiense	Chordata		8.3	0.7	0.1			0.1
Byblis millsi	Arthropoda				1.2	1.8		0.2
Caecognathia crenulatifrons	Arthropoda			0.2		3.5	0.1	2.3
Caesia perpinguis	Mollusca	0.5			0.1	0.1	0.2	0.4
Callianax baetica	Mollusca	1.0	9.0	1.5	0.8	0.3	0.5	0.7
Calliostoma tricolor	Mollusca						0.1	
Calyptraea fastigiata	Mollusca		1.5			0.1		0.1
Campylaspis biplicata	Arthropoda				0.1			
Campylaspis canaliculata	Arthropoda				0.2	0.3		0.2
Campylaspis hartae	Arthropoda			0.1	0.1			0.1
Campylaspis maculinodulosa	Arthropoda							0.2
Cancridae	Arthropoda			<0.1				0.1
Capitella teleta	Annelida					0.5		0.1
Caprella californica	Arthropoda			0.3				
Caprella mendax	Arthropoda			0.1	0.9	1.1		0.3
Caprella penantis	Arthropoda			0.1				
Caprella sp	Arthropoda			0.9				<0.1
Caprellidae	Arthropoda				0.6			0.1
Caprellinae	Arthropoda					0.6		

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Carazziella sp A	Annelida							<0.1
Cardiomya pectinata	Mollusca				0.1	1.3		
Cardiomya planetica	Mollusca				0.1			
Caridea	Arthropoda						0.1	
Carinoma mutabilis	Nemertea		10.0	2.3	0.3	0.1	1.1	0.6
Carinomella lactea	Nemertea							<0.1
Caulleriella pacifica	Annelida		1.8	0.3				
Cerapus tubularis complex	Arthropoda			0.2	0.1		0.6	0.6
Cerebratulus californiensis	Nemertea		0.3	<0.1	0.1			<0.1
Ceriantharia	Cnidaria		0.5	0.2	0.1	0.3		0.2
Chaetoderma marinelli	Mollusca					0.1		
Chaetopteridae	Annelida							0.1
Chaetozone corona	Annelida						0.2	4.1
Chaetozone hartmanae	Annelida					3.8		0.1
Chaetozone sp	Annelida			0.2	0.2	0.6	0.2	0.6
Chaetozone sp SD1	Annelida				0.1			
Chaetozone sp SD2	Annelida			3.0	0.8	4.4	0.1	0.1
Chaetozone sp SD5	Annelida		1.3	0.5	0.3	0.3	1.3	1.1
Chauliopleona dentata	Arthropoda					0.6		
Chiridota sp	Echinodermata					0.3		0.1
Chloeia pinnata	Annelida					0.3		
Chone albocincta	Annelida				0.1	0.4		0.2
Chone bimaculata	Annelida				0.2			
Chone ecaudata	Annelida		0.3	<0.1				0.1
Chone paramollis	Annelida		2.0	4.3	0.4	0.1	0.2	1.1
Chone sp	Annelida			0.1		0.4		
Chone sp B	Annelida		0.3		1.2	0.5		<0.1
Chone trilineata	Annelida		0.3			2.4		
Chone veleronis	Annelida	0.5		1.6		2.8	0.9	3.4
Cirratulidae	Annelida		0.3			0.1	0.1	0.1
Cirriformia sp	Annelida			0.1				
Cirrophorus furcatus	Annelida			0.2		0.3	0.1	0.2
Clymenella complanata	Annelida			0.3	0.5	0.1	0.1	
Clymenella sp	Annelida			0.6	0.6			
Clymenella sp A	Annelida			0.2	0.8			
Clymenella sp SD1	Annelida			<0.1			0.2	
Clymenura gracilis	Annelida			<0.1		4.9	0.1	<0.1
Cnemidocarpa rhizopus	Chordata		0.5	1.4	1.2	0.4	0.1	0.1
Compsomyax subdiaphana	Mollusca					0.3	0.3	0.5
Cooperella subdiaphana	Mollusca		0.3	0.4			1.9	1.4
Copepoda	Arthropoda						0.1	<0.1
Corophiida	Arthropoda					0.3		<0.1
Corymorpha bigelowi	Cnidaria					0.1		0.1
Cossura candida	Annelida							0.4
Cossura sp	Annelida							0.1
Cossura sp A	Annelida			<0.1				0.2
Crangon alaskensis	Arthropoda							<0.1
Crangon alba	Arthropoda			<0.1	0.1			
Crangon sp	Arthropoda			<0.1	0.1			0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Crassispira semiinflata	Mollusca							<0.1
Crepidula sp	Mollusca			<0.1			0.5	0.1
Cryptonemertes actinophila	Nemertea			0.1				<0.1
Cumanotus fernaldi	Mollusca					0.1		<0.1
Cumella californica	Arthropoda							<0.1
Cumella sp SD1	Arthropoda							0.1
Cyathodonta pedroana	Mollusca						0.1	0.2
Cyclaspis nubila	Arthropoda			<0.1	0.9			
Cyclocardia sp	Mollusca				0.1			
Cyclocardia ventricosa	Mollusca				0.8			
Cylichna diegensis	Mollusca			0.8	1.0	0.8	0.5	2.0
Cylindroleberididae	Arthropoda				0.3			<0.1
Dactylopleustes sp A	Arthropoda							<0.1
Decamastus gracilis	Annelida						0.5	0.3
Deflexilodes norvegicus	Arthropoda					0.1		
Deilocerus planus	Arthropoda		3.5	<0.1				
Dendraster terminalis	Echinodermata		2.3	4.2	0.1		0.1	<0.1
Dendrochirotida	Echinodermata							<0.1
Dentalium neohexagonum	Mollusca							<0.1
Dentalium vallicolens	Mollusca				0.3			
Diastylis californica	Arthropoda			<0.1		0.1		0.5
Diastylis crenellata	Arthropoda					0.1		0.1
Diastylis santamariensis	Arthropoda		0.3					<0.1
Diastylopsis tenuis	Arthropoda						0.2	
Diopatra ornata	Annelida						0.2	0.3
Diopatra sp	Annelida		0.5	0.6	0.6	0.1	0.5	2.6
Diopatra splendidissima	Annelida			<0.1			0.1	
Diopatra tridentata	Annelida		0.3	0.6		0.1	1.4	2.0
Diplodonta sericata	Mollusca				0.1			
Dipolydora socialis	Annelida		0.5	0.1	0.3	0.9	1.7	3.0
Dipolydora sp	Annelida					0.1	0.1	
Dorvillea (*Schistomeringos*) sp	Annelida		0.5	<0.1				
Dorvilleidae	Annelida							<0.1
Doto sp	Mollusca							<0.1
Dougaloplus sp A	Echinodermata					0.4		
Drilonereis falcata	Annelida					0.1	0.1	0.1
Drilonereis sp	Annelida				0.1		0.1	0.3
Echinoidea	Echinodermata			<0.1	0.1			
Eclysippe trilobata	Annelida			<0.1		0.3		
Edotia sp B	Arthropoda				0.1			0.1
Edotia sublittoralis	Arthropoda		0.5	0.5	1.1		0.9	0.4
Edwardsia sp G	Cnidaria		0.5	<0.1			0.1	0.1
Edwardsiidae	Cnidaria		3.0	0.5			0.2	0.1
Ennucula tenuis	Mollusca					7.4		
Enopla	Nemertea		1.3	0.3	0.2		0.1	0.2
Ensis myrae	Mollusca						0.1	<0.1
Enteropneusta	Chordata		0.3	<0.1		0.1		0.2
Epitoniidae	Mollusca							<0.1
Epitonium bellastriatum	Mollusca			<0.1		0.1		0.2

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Epitonium sawinae	Mollusca				0.1	0.1		<0.1
Eranno bicirrata	Annelida							<0.1
Eranno lagunae	Annelida							<0.1
Ericthonius brasiliensis	Arthropoda			0.1				0.1
Eteone brigitteae	Annelida			<0.1				
Eteone leptotes	Annelida						0.1	
Eteone pigmentata	Annelida				0.1		0.1	0.1
Euchone arenae	Annelida		1.0	0.3	1.2	0.6	0.5	0.1
Euchone hancocki	Annelida			0.6				0.1
Euchone incolor	Annelida			0.2		1.0		0.1
Euchone sp	Annelida			0.2		0.1	0.1	
Euclymeninae	Annelida		3.8	0.7	1.8	1.4	2.4	1.6
Euclymeninae sp A	Annelida	1.5	0.3	1.0	1.4	7.6	6.4	21.2
Eulalia californiensis	Annelida		0.3				0.1	<0.1
Eulima raymondi	Mollusca							<0.1
Eulimidae	Mollusca					0.1		
Eulithidium substriatum	Mollusca		0.3				0.1	<0.1
Eumida longicornuta	Annelida			0.2			1.0	0.4
Eunice americana	Annelida				0.1	0.6		0.1
Euphilomedes carcharodonta	Arthropoda	1.5		1.7	0.2	3.8	2.4	7.5
Euphilomedes producta	Arthropoda					0.3		
Euphysa sp A	Cnidaria			<0.1	0.1	0.1	0.7	0.2
Eupolymnia heterobranchia	Annelida			0.1		0.1		0.2
Eurydice caudata	Arthropoda			1.6	4.3	0.6		0.1
Eusarsiella thominx	Arthropoda							0.3
Eusirus sp	Arthropoda				0.1			
Eusyllis blomstrandi	Annelida				0.1			<0.1
Eusyllis habei	Annelida			0.1		0.3		
Eusyllis sp SD2	Annelida			0.1	7.3			
Eusyllis transecta	Annelida			0.1			0.1	0.3
Exogone dwisula	Annelida			0.1		0.9		0.9
Exogone lourei	Annelida		0.3	2.3	0.8	0.3	1.0	0.7
Exogone molesta	Annelida			<0.1				
Exosphaeroma rhomburum	Arthropoda			0.1				
Eyakia robusta	Arthropoda					0.3		
Fabia subquadrata	Arthropoda							<0.1
Fabricinuda limnicola	Annelida					13.5		
Fabriciola sp	Annelida					0.1		
Falcidens longus	Mollusca							0.1
Flabelligera infundibularis	Annelida		0.5					
Foxiphalus cognatus	Arthropoda							0.1
Foxiphalus golfensis	Arthropoda			<0.1			0.1	0.9
Foxiphalus obtusidens	Arthropoda		1.0	1.5	1.2	0.1	0.3	1.8
Foxiphalus similis	Arthropoda							0.2
Gadila aberrans	Mollusca	0.5	0.3	0.2		0.8	2.7	4.6
Galathowenia pygidialis	Annelida					0.3		
Gammaropsis martesia	Arthropoda					0.1		
Gammaropsis thompsoni	Arthropoda			0.2			1.1	0.4
Garosyrrhoe bigarra	Arthropoda			<0.1	0.3	0.1		

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group						
		A	B	C	D	E	F	G
Gastropoda	Mollusca				0.1	0.1		0.1
Gastropteron pacificum	Mollusca					0.1		0.1
Gibberosus myersi	Arthropoda			0.2			0.4	0.2
Gitana calitemplado	Arthropoda							<0.1
Glossaulax reclusianus	Mollusca				0.1		0.1	0.1
Glottidia albida	Brachiopoda				0.1	0.4	0.1	0.2
Glycera americana	Annelida		0.5	0.1		0.5	0.1	0.2
Glycera macrobranchia	Annelida						0.4	0.5
Glycera nana	Annelida				0.1	2.1		0.1
Glycera oxycephala	Annelida			6.5	1.9	0.1	0.1	1.2
Glycera tesselata	Annelida							0.1
Glyceridae	Annelida							<0.1
Glycinde armigera	Annelida		0.5	1.1	0.3	0.6	8.5	4.4
Glycymeris septentrionalis	Mollusca				0.1			
Goniada littorea	Annelida						0.5	
Goniada maculata	Annelida		0.3	0.1	0.8	0.6	0.4	0.6
Gymnonereis crosslandi	Annelida					0.1		
Halcampa decemtentaculata	Cnidaria		0.8	0.5	0.9	0.1		<0.1
Halianthella sp A	Cnidaria				0.1			
Halicoides synopiae	Arthropoda			<0.1	0.2	1.0		
Haliophasma geminatum	Arthropoda		0.3	0.2	0.1	1.0	0.1	0.7
Halistylus pupoideus	Mollusca			0.5	0.1			0.1
Halosydna johnsoni	Annelida						0.1	
Hamatoscalpellum californicum	Arthropoda			<0.1		0.1		<0.1
Harpacticoida	Arthropoda							<0.1
Hartmanodes hartmanae	Arthropoda			0.6			0.1	0.3
Hartmanodes sp SD1	Arthropoda			<0.1	0.5			<0.1
Hemilamprops californicus	Arthropoda			2.4	0.5	0.1	0.1	3.1
Hemipodia borealis	Annelida		14.0	<0.1				0.1
Hemiproto sp A	Arthropoda					1.0		
Hesionura coineaui difficilis	Annelida		11.0	0.3	0.3			<0.1
Heteromastus filobranchus	Annelida							<0.1
Heteronemertea	Nemertea							<0.1
Heteronemertea sp SD2	Nemertea			0.2	0.2			0.2
Heterophoxus oculatus	Arthropoda							<0.1
Heteropodarke heteromorpha	Annelida			0.3	0.1			
Heteroserolis carinata	Arthropoda		0.5	0.1	0.1			0.1
Heterospio catalinensis	Annelida							0.2
Hippomedon sp A	Arthropoda				0.1			<0.1
Hippomedon zetesimus	Arthropoda			0.1		0.1		0.1
Hoplonemertea sp A	Nemertea							<0.1
Hornellia occidentalis	Arthropoda		3.0					<0.1
Isocheles pilosus	Arthropoda		0.3					
Jasmineira sp B	Annelida				1.6	3.0		0.1
Joeropsis concava	Arthropoda							<0.1
Joeropsis dubia	Arthropoda						0.1	
Kurtzia arteaga	Mollusca			<0.1				0.1
Kurtziella plumbea	Mollusca	1.5	0.3	0.2	0.1		1.1	1.3
Kurtzina beta	Mollusca			<0.1		0.1		0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group						
		A	B	C	D	E	F	G
Lacydonia sp	Annelida		0.3					
Lamprops quadriplicatus	Arthropoda			0.1			0.1	
Lanassa venusta venusta	Annelida		0.3	0.2	11.9			0.9
Lanice conchilega	Annelida							<0.1
Laonice cirrata	Annelida			0.1		0.3	2.6	1.3
Laonice nuchala	Annelida							<0.1
Lasaeidae	Mollusca			<0.1			0.1	
Laticorophium baconi	Arthropoda				1.2		0.4	0.1
Leitoscoloplos pugettensis	Annelida			<0.1	0.2		0.1	0.3
Lepidasthenia berkeleyae	Annelida							<0.1
Lepidasthenia longicirrata	Annelida							<0.1
Lepidepecreum serraculum	Arthropoda		0.3	0.1	0.1			<0.1
Lepidopa californica	Arthropoda			0.1				
Leptochelia dubia	Arthropoda			0.9	0.6	4.0	0.9	1.5
Leptopecten latiauratus	Mollusca	0.5		0.2	0.1		0.6	1.4
Leptoplanidae	Platyhelminthes			<0.1			0.1	
Leptostylis abditis	Arthropoda					0.1		
Leptosynapta sp	Echinodermata		5.3	0.5	0.4	0.3	0.1	<0.1
Leuroleberis sharpei	Arthropoda	0.5	1.0	0.4	0.3		0.6	0.4
Levinsenia gracilis	Annelida							0.1
Levinsenia sp B	Annelida					0.9		
Liljeborgiidae	Arthropoda							<0.1
Limatula saturna	Mollusca					0.1		<0.1
Lineidae	Nemertea		1.0	0.6	0.4	1.4	0.6	0.4
Lineus bilineatus	Nemertea				0.3	0.1		
Lirobarleeia kelseyi	Mollusca				1.8			
Lirobittium larum	Mollusca							<0.1
Listriella diffusa	Arthropoda			<0.1				
Listriella goleta	Arthropoda						0.1	0.2
Listriella melanica	Arthropoda			0.1				
Listriella sp SD1	Arthropoda							0.1
Listriolobus pelodes	Echiura					0.3		
Loimia sp A	Annelida							<0.1
Lovenia cordiformis	Echinodermata			0.1	0.1			
Lucinisca nuttalli	Mollusca				0.1		0.1	0.1
Lucinoma annulatum	Mollusca							<0.1
Lumbrineridae	Annelida							<0.1
Lumbrinerides platypygos	Annelida		4.0	11.9	1.6	0.1	0.9	0.3
Lumbrineris cruzensis	Annelida			0.3	0.2	1.0		1.5
Lumbrineris latreilli	Annelida		1.8	0.2	0.5	2.3		<0.1
Lumbrineris lingulata	Annelida			0.7	1.0	4.0		0.7
Lumbrineris sp	Annelida							<0.1
Lumbrineris sp group I	Annelida		2.3	0.4	0.4	0.3	0.1	1.5
Lumbrineris sp group II	Annelida			<0.1	0.5	0.1		0.1
Lyonsia californica	Mollusca		0.3	0.9	0.7	0.3		0.4
Lyonsiidae	Mollusca			1.2	1.9	0.9	0.4	0.3
Lysippe sp A	Annelida			0.2	0.2	0.1		0.9
Lysippe sp B	Annelida					0.1		
Lytechinus pictus	Echinodermata		1.0	<0.1	0.1	0.1		

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Macoma nasuta	Mollusca			0.1				<0.1
Macoma sp	Mollusca						0.1	0.1
Macoma yoldiformis	Mollusca			0.4		0.1	1.1	2.1
Mactridae	Mollusca			0.1				
Magelona berkeleyi	Annelida					0.1		0.3
Magelona hartmanae	Annelida							0.1
Magelona hobsonae	Annelida			<0.1				
Magelona sacculata	Annelida		0.8	0.3			0.1	0.1
Magelona sp	Annelida							0.1
Magelona sp A	Annelida					0.1		
Majoidea	Arthropoda						0.1	0.1
Malacoceros indicus	Annelida				0.1	0.3		
Maldane sarsi	Annelida					1.8		<0.1
Maldanidae	Annelida			1.8	1.8	0.6	1.6	2.3
Maldaninae	Annelida			0.4	0.2			<0.1
Malmgreniella baschi	Annelida			<0.1				<0.1
Malmgreniella macginitiei	Annelida							0.1
Malmgreniella sp	Annelida					0.1		0.1
Malmgreniella sp A	Annelida		1.8	<0.1	0.1	0.1	0.1	0.1
Mandibulophoxus gilesi	Arthropoda		0.3	<0.1				
Mangelia hexagona	Mollusca				0.1			
Marphysa disjuncta	Annelida				0.1			
Marphysa sp	Annelida					0.1		<0.1
Mayerella banksia	Arthropoda		0.3	<0.1		0.1	0.2	0.3
Mediomastus acutus	Annelida			<0.1			0.1	0.2
Mediomastus sp	Annelida	0.5	11.3	1.6	0.2	2.9	6.4	9.1
Megalomma pigmentum	Annelida			0.1	0.1	0.1	0.1	0.4
Megalomma sp	Annelida						0.1	0.2
Megaluropidae sp A	Arthropoda				0.9	0.1		
Megasurcula carpenteriana	Mollusca				0.1			<0.1
Melanella rosa	Mollusca					0.6		<0.1
Melinna oculata	Annelida			<0.1		0.4	0.1	3.0
Melphisana bola complex	Arthropoda			<0.1		0.1		0.1
Mesocrangon munitella	Arthropoda							<0.1
Mesolamprops bispinosus	Arthropoda					0.4		0.1
Metacarcinus gracilis	Arthropoda						0.4	0.1
Metaphoxus frequens	Arthropoda					0.1		
Metasychis disparidentatus	Annelida					0.8		1.3
Metatiron tropakis	Arthropoda		2.8				0.1	
Metharpinia coronadoi	Arthropoda			0.6	0.4		0.2	0.1
Metharpinia jonesi	Arthropoda		0.5					
Metopa dawsoni	Arthropoda				0.1			<0.1
Micranellum crebricinctum	Mollusca		0.5	1.1	0.5		0.2	
Microjassa sp	Arthropoda				0.1	0.1		0.1
Microphthalmus sp	Annelida		0.3	<0.1				
Micropodarke dubia	Annelida		12.5					
Micrura alaskensis	Nemertea			0.1	0.2			0.1
Micrura sp	Nemertea				0.1			
Modiolus neglectus	Mollusca							<0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Modiolus sp	Mollusca			<0.1	0.1		0.3	0.2
Molgula pugetiensis	Chordata			0.1	0.5			
Molgula regularis	Chordata					0.5		
Molgula sp	Chordata			0.1	0.1	0.1		<0.1
Molgula sp SD1	Chordata			0.1				0.1
Molpadia intermedia	Echinodermata					0.1		
Monoculodes emarginatus	Arthropoda					0.9		
Monostyliferoidea	Nemertea		1.8	<0.1	0.4		0.2	0.2
Monticellina cryptica	Annelida			<0.1	0.1	1.1		0.5
Monticellina siblina	Annelida		0.8	1.5		1.1	1.8	38.7
Monticellina sp	Annelida			<0.1				0.1
Monticellina tesselata	Annelida							0.9
Mooreonuphis nebulosa	Annelida			0.6		0.4	0.1	18.1
Mooreonuphis sp	Annelida			1.8	9.2		0.1	1.8
Mooreonuphis sp SD1	Annelida			3.1	15.2			0.6
Mooresamytha bioculata	Annelida				0.1	0.3		
Myriochele gracilis	Annelida					25.6		
Myriochele striolata	Annelida				0.5	4.6		1.2
Mysidae	Arthropoda							<0.1
Mysidopsis intii	Arthropoda							<0.1
Mystides sp	Annelida							0.1
Myxicola sp	Annelida							0.1
Naineris uncinata	Annelida						0.1	0.2
Neastacilla californica	Arthropoda		0.3	<0.1	0.1	0.1	0.1	0.3
Nebalia daytoni	Arthropoda							0.1
Nebalia pugettensis complex	Arthropoda			0.1				<0.1
Nematoda	Nematoda	1.5	3.0	1.3	1.5		0.6	1.0
Nemertea	Nemertea			<0.1			0.1	
Nemocardium centifilosum	Mollusca					0.4		
Neocrangon sp	Arthropoda					0.1		
Neolepton salmoneum	Mollusca			<0.1				<0.1
Neomysis kadiakensis	Arthropoda							0.2
Neosabellaria cementarium	Annelida			0.2				0.3
Neotrypaea sp	Arthropoda						0.1	<0.1
Nephasoma diaphanes	Sipuncula				0.1			
Nephtys caecoides	Annelida		0.5	0.8	0.3	0.4	0.7	1.0
Nephtys cornuta	Annelida							0.4
Nephtys ferruginea	Annelida			<0.1	0.1	0.5		0.2
Nephtys sp	Annelida							<0.1
Nephtys sp SD2	Annelida			<0.1	0.2			
Nereididae	Annelida			<0.1			0.1	<0.1
Nereiphylla sp 2	Annelida			<0.1	0.1		0.1	0.1
Nereis latescens	Annelida						0.1	
Nereis sp A	Annelida		0.8	1.4	0.2	0.1	1.2	5.1
Nodiscala spongiosa	Mollusca			<0.1				
Notocirrus californiensis	Annelida							<0.1
Notomastus latericeus	Annelida		0.8	17.7	0.1	0.9	0.8	10.5
Notomastus lineatus	Annelida		0.3	<0.1				
Notomastus sp	Annelida						0.1	0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Notomastus sp A	Annelida		0.5	0.1		0.3		0.5
Nuculana hamata	Mollusca					1.0		
Nuculana penderi	Mollusca						0.1	
Nuculana sp	Mollusca							<0.1
Nuculana sp A	Mollusca					0.6		
Nuculana taphria	Mollusca	1.5		0.1			4.6	5.3
Odontosyllis phosphorea	Annelida		0.3	<0.1	0.4		0.1	0.7
Odontosyllis sp SD1	Annelida		0.3					
Odostomia sp	Mollusca	1.0		0.1			0.6	1.0
Oenonidae	Annelida						0.1	
Oerstedia dorsalis	Nemertea			<0.1	0.1	0.3		0.2
Oligochaeta	Annelida		4.3		0.1			
Onuphidae	Annelida			1.2	6.3	0.3	0.4	1.3
Onuphis elegans	Annelida			0.1				
Onuphis eremita parva	Annelida			0.2			0.1	0.1
Onuphis sp	Annelida			0.3	0.1	0.1	0.1	0.3
Onuphis sp A	Annelida		1.3	1.7	1.1	0.8	1.9	3.4
Ophelia pulchella	Annelida		1.5	2.0	0.9		0.4	
Ophelina acuminata	Annelida					0.1		
Ophelina sp SD1	Annelida						0.1	
Ophiodermella inermis	Mollusca			0.1		0.3	0.2	0.2
Ophiodromus pugettensis	Annelida		0.5		0.1			
Ophiothrix spiculata	Echinodermata							0.1
Ophiura luetkenii	Echinodermata				0.1	1.0		0.1
Ophiuroconis bispinosa	Echinodermata			3.6	10.9	3.6		3.0
Ophiuroidea	Echinodermata			<0.1		0.4		0.1
Orchomene anaquelus	Arthropoda							<0.1
Orchomenella decipiens	Arthropoda				0.1			
Orchomenella pacifica	Arthropoda				0.2			
Owenia collaris	Annelida			<0.1			0.1	0.1
Oxyurostylis pacifica	Arthropoda	0.5		<0.1			0.4	0.2
Pachynus barnardi	Arthropoda			<0.1			0.1	<0.1
Pacifacanthomysis nephrophthalma	Arthropoda			0.1				0.1
Palaeonemertea	Nemertea		0.8	0.1	0.1	0.1	0.1	0.3
Pandora bilirata	Mollusca				0.3		0.1	
Paradiopatra parva	Annelida				0.1	1.8	0.1	0.2
Paradoneis lyra	Annelida		0.5			0.1		
Paradoneis sp	Annelida		0.3					
Paradoneis sp SD1	Annelida					1.0		<0.1
Parametopella ninis	Arthropoda				0.1			
Paranaitis sp SD1	Annelida			<0.1				
Parandalia fauveli	Annelida							0.1
Paranemertes californica	Nemertea			0.1	0.1	0.4	0.7	0.5
Paraonidae	Annelida		0.3	<0.1				0.1
Paraprionospio alata	Annelida					0.1	0.5	1.6
Pareurythoe californica	Annelida		73.0					0.1
Parougia caeca	Annelida			0.1			0.1	0.4
Parvilucina tenuisculpta	Mollusca			0.3	0.1	3.1		0.6
Pectinaria californiensis	Annelida					0.9	0.1	0.4

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Pectinaria granulata	Annelida		0.3					
Pectinidae	Mollusca						0.1	
Penaeoidea	Arthropoda						0.1	
Pentactinia californica	Cnidaria				0.2			
Pentamera lissoplaca	Echinodermata							0.1
Pentamera populifera	Echinodermata						0.3	0.1
Pentamera pseudopopulifera	Echinodermata			<0.1		0.1		0.4
Pentamera sp	Echinodermata					0.4	0.9	0.3
Periploma discus	Mollusca							0.1
Periploma sp	Mollusca					0.1		0.3
Petaloclymene pacifica	Annelida			<0.1	0.1			2.0
Phascolion sp A	Sipuncula					1.8		0.3
Pherusa negligens	Annelida							<0.1
Pherusa neopapillata	Annelida		1.0	0.2		0.4	0.1	1.6
Philine auriformis	Mollusca			<0.1				
Philinoglossa sp A	Mollusca		3.0					
Phisidia sanctaemariae	Annelida					1.5		<0.1
Pholoe glabra	Annelida					0.5		0.1
Pholoides asperus	Annelida			<0.1			0.1	
Phorona	Phorona			0.1				<0.1
Phoronis sp	Phorona			0.5	0.1	1.6		0.2
Phoronis sp SD1	Phorona						0.1	0.1
Phoronopsis sp	Phorona		1.3	0.2	0.1	0.4		
Photis bifurcata	Arthropoda				0.1			<0.1
Photis brevipes	Arthropoda			2.3	0.7		1.8	1.6
Photis californica	Arthropoda				0.5	2.9		0.6
Photis lacia	Arthropoda				0.1	0.6		
Photis macinerneyi	Arthropoda			0.2			0.7	
Photis sp	Arthropoda		2.0	0.8		0.1	1.2	0.7
Photis sp C	Arthropoda					0.9		0.1
Photis sp OC1	Arthropoda			0.1		0.3	2.4	0.8
Phoxocephalidae	Arthropoda			<0.1				
Phyllochaetopterus limicolus	Annelida					0.1		0.1
Phyllodoce cuspidata	Annelida			<0.1		0.1		0.1
Phyllodoce groenlandica	Annelida			0.1	0.1	0.6		0.1
Phyllodoce hartmanae	Annelida		0.3	2.5	0.6	0.5	0.6	2.4
Phyllodoce longipes	Annelida			0.1			1.2	0.4
Phyllodoce medipapillata	Annelida		1.3					
Phyllodoce pettiboneae	Annelida			0.8			0.4	0.1
Phyllodoce sp	Annelida		2.0	<0.1			0.2	0.1
Phyllodocidae	Annelida		0.3					
Phyllophoridae	Echinodermata		0.3		0.1			0.1
Phyllophoridae sp A	Echinodermata		0.3					
Phylo felix	Annelida							0.1
Pinnixa franciscana	Arthropoda							0.1
Pinnixa longipes	Arthropoda						0.1	0.2
Pinnixa occidentalis complex	Arthropoda							<0.1
Pinnixa sp	Arthropoda			0.1		0.1		0.2
Pionosyllis sp SD2	Annelida				0.2			

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Piromis sp A	Annelida					0.3		
Pisione sp	Annelida		10.0		0.3			0.3
Pista brevibranchiata	Annelida				0.1	0.3		
Pista estevanica	Annelida			0.5	0.2	3.0	0.1	0.9
Pista moorei	Annelida			0.2	0.1			<0.1
Pista sp	Annelida						0.1	0.1
Pista wui	Annelida			0.2			1.0	1.7
Platymera gaudichaudii	Arthropoda							<0.1
Platynereis bicanaliculata	Annelida			0.3			0.5	0.1
Pleusymtes subglaber	Arthropoda				0.1	0.1		0.1
Podarkeopsis glabrus	Annelida							0.1
Podocerus brasiliensis	Arthropoda						0.1	
Poecilochaetus johnsoni	Annelida			<0.1	0.1			<0.1
Polycirrus californicus	Annelida		1.0					
Polycirrus sp	Annelida		9.8	0.8	2.6	0.5	0.1	0.4
Polycirrus sp A	Annelida			2.5	7.3	0.6	0.1	2.8
Polycirrus sp I	Annelida		0.8	0.1	0.8			
Polycirrus sp OC1	Annelida				0.1	0.1		0.1
Polycirrus sp SD3	Annelida		0.8		0.1	0.1		
Polydora limicola	Annelida			2.1				
Polydora sp	Annelida			0.8		0.1	0.8	<0.1
Polygireulima rutila	Mollusca			0.4	0.1			
Polygordius sp SD1	Annelida		0.3					
Polynoidae	Annelida						0.1	
Polyschides quadrifissatus	Mollusca		0.3	2.2	1.6			0.4
Postasterope barnesi	Arthropoda					0.1		
Potamethus sp A	Annelida							0.2
Prachynella lodo	Arthropoda				0.1			<0.1
Praxillella gracilis	Annelida							<0.1
Praxillella pacifica	Annelida			0.1	2.6	0.8	0.1	2.1
Prionospio (*Minuspio*) *lighti*	Annelida					0.1		0.2
Prionospio (*Prionospio*) *dubia*	Annelida				0.1	5.8		<0.1
Prionospio (*Prionospio*) *jubata*	Annelida			1.0	0.3	2.8	0.1	3.2
Procampylaspis caenosa	Arthropoda					0.4		
Proceraea sp	Annelida					0.1	0.1	<0.1
Proclea sp A	Annelida					0.1		
Propeamussiidae	Mollusca						0.1	
Protodorvillea gracilis	Annelida		4.3	4.1	0.7		1.1	0.3
Protomedeia articulata complex	Arthropoda						0.3	
Protomystides sp SD1	Annelida		2.8	<0.1				
Prototrygaeus jordanae	Arthropoda	0.5					0.4	0.4
Pseudopotamilla sp	Annelida						0.1	
Pycnogonida	Arthropoda							<0.1
Pyromaia tuberculata	Arthropoda						0.1	<0.1
Rhabdocoela sp A	Platyhelminthes		1.0					
Rhachotropis sp A	Arthropoda					0.3		
Rhamphobrachium longisetosum	Annelida					1.0		0.1
Rhepoxynius abronius	Arthropoda							0.1
Rhepoxynius daboius	Arthropoda							0.1

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Rhepoxynius fatigans	Arthropoda							0.5
Rhepoxynius heterocuspidatus	Arthropoda			1.3	0.7			<0.1
Rhepoxynius lucubrans	Arthropoda			0.2		1.9		
Rhepoxynius menziesi	Arthropoda		0.3	0.4			1.0	1.1
Rhepoxynius sp	Arthropoda					0.1		
Rhepoxynius stenodes	Arthropoda				0.1	0.1	1.6	1.0
Rhepoxynius variatus	Arthropoda			0.2		0.1	0.2	<0.1
Rhodine bitorquata	Annelida					1.0		<0.1
Rictaxis punctocaelatus	Mollusca			0.3		0.1	0.6	1.0
Rochefortia grippi	Mollusca			0.4	0.1		0.1	0.1
Rochefortia sp	Mollusca					0.1		0.1
Rochefortia tumida	Mollusca			2.6	0.7	2.4	0.7	1.5
Rudilemboides sp	Arthropoda							<0.1
Rudilemboides sp A	Arthropoda				0.1			<0.1
Rudilemboides stenopropodus	Arthropoda		0.3	0.2	0.1	0.1		0.2
Rutiderma rotundum	Arthropoda		0.3					
Sabellaria gracilis	Annelida			0.1			1.5	0.1
Sabellidae	Annelida					0.4	0.1	<0.1
Sabellides manriquei	Annelida				0.1			
Saccocirrus sp	Annelida		1.0					
Saccoglossus sp	Chordata			<0.1			0.1	0.3
Samytha californiensis	Annelida					0.3		0.1
Saxicavella pacifica	Mollusca					0.1		
Scalibregma californicum	Annelida			0.1			0.4	0.2
Scaphopoda	Mollusca			0.3	0.1		0.1	<0.1
Schistocomus hiltoni	Annelida							0.1
Schistocomus sp	Annelida				0.1			<0.1
Schistocomus sp A	Annelida			0.2			2.0	0.3
Schizocardium sp	Chordata			<0.1		0.1		<0.1
Scolelepis (*Scolelepis*) *occidentalis*	Annelida				0.1			
Scoletoma tetraura complex	Annelida				0.1	0.1	1.0	0.7
Scoloplos acmeceps	Annelida			1.0	0.4		0.1	0.2
Scoloplos armiger complex	Annelida		4.0	5.2	2.0	2.5	0.1	1.8
Scoloplos sp	Annelida			0.2				
Sigalion spinosus	Annelida	0.5	0.8	0.9	3.1	1.5	1.1	2.4
Sige sp A	Annelida		1.5	<0.1	0.1			0.1
Simomactra planulata	Mollusca		0.8	0.3	0.5			0.1
Sipuncula	Sipuncula			<0.1	0.1			
Solamen columbianum	Mollusca			1.5	1.4	3.9	0.2	0.3
Solariella peramabilis	Mollusca				1.6		0.1	
Solemya reidi	Mollusca					1.3		0.3
Solen sicarius	Mollusca			0.2		1.0	0.4	0.5
Sphaerephesia similisetis	Annelida					0.1		
Sphaerosyllis californiensis	Annelida		0.8	<0.1	0.1		0.9	0.1
Spio filicornis	Annelida				0.1	0.5		0.1
Spio maculata	Annelida		6.5	4.8	9.4		0.2	0.3
Spiochaetopterus costarum complex	Annelida			0.2	0.1	0.1	0.7	0.4
Spionidae	Annelida			0.1				0.1
Spiophanes berkeleyorum	Annelida			0.8	0.8	0.6	0.9	9.4

Appendix D.1 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Spiophanes norrisi	Annelida	1.0	20.8	196.8	54.6	18.8	32.9	80.7
Spiophanes duplex	Annelida	1.0	2.8	1.3		3.0	42.7	8.0
Spiophanes sp	Annelida						0.1	0.1
Stenothoides bicoma	Arthropoda			0.1			0.1	<0.1
Stereobalanus sp	Chordata			<0.1		0.5	0.1	0.1
Sternaspis fossor	Annelida					0.6		0.4
Sthenelais sp	Annelida		0.3	<0.1			0.1	0.1
Sthenelais tertiaglabra	Annelida					0.8	0.1	1.0
Sthenelais verruculosa	Annelida						0.3	0.2
Sthenelanella uniformis	Annelida			<0.1		2.8		0.7
Stolidobranchiata	Chordata			0.1	0.1			<0.1
Streblosoma crassibranchia	Annelida					1.6		0.4
Streblosoma sp	Annelida			0.2	0.9	0.3	0.3	0.5
Streblosoma sp B	Annelida			0.1	1.1	1.3	0.4	1.7
Streblosoma sp SD1	Annelida					0.4		
Streblosoma sp SF1	Annelida			0.1	0.2		0.2	0.3
Streptosyllis sp SD1	Annelida			<0.1				
Stylatula elongata	Cnidaria			<0.1				
Stylatula sp	Cnidaria	0.5		<0.1			0.1	0.1
Stylatula sp A	Cnidaria		0.3	<0.1				
Stylochoplana sp HYP2	Platyhelminthes			<0.1				
Stylochus exiguus	Platyhelminthes						0.1	<0.1
Syllides reishi	Annelida		0.5					
Synidotea magnifica	Arthropoda			0.2				1.5
Tanaidacea	Arthropoda				0.1			
Tellina bodegensis	Mollusca			<0.1				
Tellina cadieni	Mollusca					0.1		0.1
Tellina carpenteri	Mollusca					3.1		
Tellina idae	Mollusca							0.2
Tellina modesta	Mollusca			1.2	0.1	0.3	2.7	5.7
Tellina nuculoides	Mollusca			0.1				
Tellinidae	Mollusca					0.1		
Tenonia priops	Annelida		0.3	0.3	0.2	0.1	0.4	0.3
Terebellidae	Annelida					0.4	0.1	<0.1
Terebellides californica	Annelida					1.1		0.2
Tetrastemma albidum	Nemertea					0.4	0.1	
Tetrastemma candidum	Nemertea	0.5			0.3		0.1	<0.1
Tetrastemma nigrifrons	Nemertea			0.1			0.1	0.1
Tetrastemma sp	Nemertea			<0.1				0.1
Thracia trapezoides	Mollusca					0.1		
Thraciidae	Mollusca							0.3
Thracioidea	Mollusca					0.1		0.1
Thyasira flexuosa	Mollusca					0.5		0.1
Thysanocardia nigra	Sipuncula			0.1	0.8	0.6	0.1	0.2
Tiburonella viscana	Arthropoda		0.3	<0.1				
Tiron biocellata	Arthropoda			0.2			0.9	0.6
Trachycardium quadragenarium	Mollusca							<0.1
Travisia brevis	Annelida					0.4		<0.1
Tritella pilimana	Arthropoda						0.1	

Appendix D.1 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Tubulanidae	Nemertea			<0.1		0.1	0.1	0.3
Tubulanidae sp B	Nemertea							0.1
Tubulanus cingulatus	Nemertea			0.3		0.8	0.1	0.2
Tubulanus polymorphus	Nemertea			0.6	0.1	1.4	1.1	2.6
Tubulanus sp	Nemertea							0.1
Tubulanus sp A	Nemertea					0.4	0.1	0.4
Turbonilla sp	Mollusca		0.3				0.1	0.1
Turbonilla sp A	Mollusca			0.1	0.1		0.2	0.1
Turbonilla sp SD1	Mollusca				0.1	0.1	0.5	1.2
Turbonilla sp SD2	Mollusca						0.1	0.1
Turbonilla sp SD5	Mollusca				0.1			<0.1
Turbonilla sp SD6	Mollusca			0.1			0.1	0.1
Turbonilla sp SD7	Mollusca				0.1			
Typosyllis farallonensis	Annelida	0.5					0.4	0.4
Typosyllis heterochaeta	Annelida			0.4		1.1		0.5
Typosyllis hyperioni	Annelida					0.4		
Typosyllis sp	Annelida				0.1		0.1	
Typosyllis sp SD1	Annelida		20.8	0.1	2.6			
Typosyllis sp SD2	Annelida		0.8	4.7	1.8		0.1	
Typosyllis sp SD6	Annelida		0.3					
Venerinae	Mollusca						0.2	<0.1
Virgularia californica	Cnidaria							<0.1
Virgularia sp	Cnidaria							<0.1
Volvulella californica	Mollusca							0.1
Volvulella cylindrica	Mollusca	0.5		0.1		0.3	0.6	0.4
Volvulella panamica	Mollusca							0.2
Volvulella sp	Mollusca	0.5					0.1	0.1
Westwoodilla tone	Arthropoda		1.0	0.2		0.4	0.1	0.8
Xenoleberis californica	Arthropoda				0.1		0.1	0.1
Zaolutus actius	Cnidaria							0.1
Zygeupolia rubens	Nemertea			0.1				

Appendix E

Supporting Data

2009 SBOO Stations

Demersal Fishes and Megabenthic Invertebrates

Appendix E.1

Summary of demersal fish species captured during 2009 at SBOO stations. Data are number of fish (*n*), biomass (BM; kg, wet weight), minimum (Min), maximum (Max), and mean length (cm, standard length). Taxonomic arrangement and scientific names are of Eschmeyer and Herald (1998) and Allen (2005).

						Length	
Taxon/Species			**Common Name**	***n***	**BM**	**Min**	**Max**	**Mean**
RAJIFORMES								
	Rajidae							
		Raja inornata	California skate	6	3	17	48	33
CLUPERIFORMES								
	Engraulidae							
		Engraulis mordax	northern anchovy	1	0	13	13	13
AULOPIFORMES								
	Synodontidae							
		Synodus lucioceps	California lizardfish	1791	18	6	30	10
OPHIDIIFORMES								
	Ophidiidae							
		Chilara taylori	spotted cuskeel	2	0	12	17	15
BATRACHOIDIFORMES								
	Batrachoididae							
		Porichthys notatus	plainfin midshipman	33	2	2	26	10
		Porichthys myriaster	specklefin midshipman	5	0	3	15	10
SYNGNATHIFORMES								
	Syngnathidae							
		Snygnathus californiensis	kelp pipefish	1	0	17	17	17
		Syngnathus exilis	barcheek pipefish	2	0	17	19	18
		Syngnathus leptorhynchus	bay pipefish	2	0	26	26	26
SCORPAENIFORMES								
	Scorpaenidae		unidentified juvenile	3	0	3	5	4
		Scorpaena guttata	California scorpionfish	24	9	13	45	21
	Hexagrammidae							
		Zaniolepis latipinnis	longspine combfish	110	4	12	16	13
	Cottidae							
		Chitonotus pugetensis	roughback sculpin	533	8	4	11	8
		Icelinus quadriseriatus	yellowchin sculpin	934	6	3	8	7
	Agonidae							
		Odontopyxis trispinosa	pygmy poacher	7	0	7	9	8
PERCIFORMES								
	Serranidae		unidentified juvenile	1	0	3	3	3
		Paralabrax clathratus	kelp bass	1	0	7	7	7
	Sciaenidae							
		Genyonemus lineatus	white croaker	2	0	15	16	16
	Embiotocidae							
		Cymatogaster aggregata	shiner perch	19	0	8	10	9
		Zalembius rosaceus	pink seaperch	4	0	5	5	5
	Labridae							
		Oxyjulis californica	señorita	1	0	10	10	10
	Clinidae							
		Heterostichus rostratus	giant kelpfish	1	0	11	11	11
	Chaenopsidae							
		Neoclinus blanchardi	sarcastic fringehead	3	0	3	12	7

Appendix E.1 *continued*

Taxon/Species			Common Name	*n*	BM	Length		
						Min	Max	Mean
	Stromateidae							
		Peprilus simillimus	Pacific pompano	4	1	9	13	10
PLEURONECTIFORMES								
	Paralichthyidae							
		Citharichthys sordidus	Pacific sanddab	1	0	12	12	12
		Citharichthys stigmaeus	speckled sanddab	2364	20	3	12	7
		Citharichthys xanthostigma	longfin sanddab	146	10	5	19	13
		Hippoglossina stomata	bigmouth sole	3	0	17	18	18
		Paralichthys californicus	California halibut	4	4	25	42	33
		Xystreurys liolepis	fantail sole	12	3	5	29	17
	Pleuronectidae							
		Parophrys vetulus	English sole	15	2	13	26	18
		Pleuronichthys ritteri	spotted turbot	1	0	15	15	15
		Pleuronichthys verticalis	hornyhead turbot	89	9	4	21	12
	Cynoglossidae							
		Symphurus atricaudus	California tonguefish	67	2	6	16	11

Appendix E.2

Summary of total abundance by species and station for demersal fishes at the SBOO stations during 2009.

	January 2009							Species Abundance by Survey
Name	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	55	119	60	101	104	99	55	593
California lizardfish	6	8	12	58	8	7	36	135
Roughback sculpin	8	31	13	28	14	15	12	121
Longspine combfish			1	14		2	22	39
Shiner perch				6			13	19
California tonguefish			3	6	4	2	2	17
Hornyhead turbot		3	1	1	2	1	8	16
Plainfin midshipman		2	1		1		3	7
Longfin sanddab			1	3			1	5
Fantail sole	1					1	1	3
Sarcastic fringehead	3							3
Specklefin midshipman				1	1		1	3
Barcheek pipefish						2		2
English sole			1	1				2
California halibut	1							1
California skate					1			1
Giant kelpfish							1	1
Kelp bass							1	1
Kelp pipefish	1							1
Señorita				1				1
Spotted turbot		1						1
Quarter Total	75	164	93	220	135	129	156	972

Appendix E.2 *continued*

Name	April 2009							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	125	79	68	66	50	77	69	534
Roughback sculpin	21	32	21	33	6	18	33	164
California lizardfish	1	3	1	10	37	69	19	140
Yellowchin sculpin			38	54	6		15	113
Longspine combfish		1		40	3	2	17	63
Longfin sanddab		2	12	3	3		4	24
Hornyhead turbot	3	2	3	4		1	6	19
English sole	3		1	3		1	1	9
California tonguefish		3	2				1	6
Plainfin midshipman				2	1	1	2	6
Fantail sole			2				2	4
Pacific pompano					4			4
Pink seaperch			1		2	1		4
California scorpionfish				1		1	1	3
Unidentified rockfish					2		1	3
Bay pipefish			2					2
California skate			1	1				2
Pygmy poacher			2					2
Specklefin midshipman				2				2
California halibut		1						1
Northern anchovy					1			1
Unidentified sea bass							1	1
Quarter Total	153	123	154	219	115	171	172	1107

Appendix E.2 *continued*

Name	July 2009							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	107	161	167	65	66	115	151	832
Yellowchin sculpin		60	169	29	81	122	140	601
California lizardfish	66	83	99	34	43	76	106	507
Roughback sculpin	3	25	14	1	27	39	14	123
Longfin sanddab		21		2	31	14	31	99
California tonguefish		1	3	1	2	3	18	28
Hornyhead turbot	4	3	7	1	1	3	8	27
Plainfin midshipman		1	1		2	5		9
California scorpionfish			1	2	1			4
English sole	1		1		1	1		4
Fantail sole				1		2		3
Pygmy poacher			2				1	3
California halibut		1				1		2
California skate	1						1	2
Longspine combfish					1		1	2
Spotted cuskeel			1				1	2
Bigmouth sole							1	1
Pacific sanddab						1		1
Quarter Total	182	356	465	136	256	382	473	2250

Appendix E.2 *continued*

Name	October 2009							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
California lizardfish	72	26	371	162	316	53	9	1009
Speckled sanddab	69	66	65	122	32	36	15	405
Yellowchin sculpin	1	5	30	31	40	99	14	220
Roughback sculpin		2	41	30	9	33	10	125
Hornyhead turbot	2	4	5	5	2	6	3	27
Longfin sanddab		3		1	11	2	1	18
California scorpionfish	1	4	3	3			6	17
California tonguefish				1	3	11	1	16
Plainfin midshipman					1	6	4	11
Longspine combfish						2	4	6
Bigmouth sole			1	1				2
Fantail sole	1		1					2
Pygmy poacher			1			1		2
White croaker							2	2
California skate						1		1
Quarter Total	146	110	518	356	414	250	69	1863
Annual Total	**556**	**753**	**1230**	**931**	**920**	**932**	**870**	**6192**

Appendix E.3

Summary of biomass (kg) by species and station for demersal fishes at the SBOO stations during 2009.

Name	January 2009							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	0.5	1.0	0.5	0.5	1.1	0.3	0.4	4.3
California lizardfish	0.3	0.2	0.2	1.3	0.1	0.2	0.9	3.2
Roughback sculpin	0.1	0.3	0.1	1.2	0.2	0.2	0.2	2.3
Longspine combfish			0.1	0.5		0.1	0.7	1.4
Hornyhead turbot		0.1	0.1	0.1	0.2	0.1	0.5	1.1
California halibut	1.1							1.1
Longfin sanddab			0.1	0.3			0.1	0.5
California tonguefish			0.1	0.1	0.1	0.1	0.1	0.5
Shiner perch				0.1			0.3	0.4
Fantail sole	0.1					0.2	0.1	0.4
Plainfin midshipman		0.1	0.1		0.1		0.1	0.4
English sole			0.2	0.1				0.3
Specklefin midshipman				0.1	0.1		0.1	0.3
Barcheek pipefish						0.1		0.1
California skate					0.1			0.1
Giant kelpfish							0.1	0.1
Kelp bass							0.1	0.1
Kelp pipefish	0.1							0.1
Sarcastic fringehead	0.1							0.1
Señorita				0.1				0.1
Spotted turbot		0.1						0.1
Quarter Total	2.3	1.8	1.5	4.4	2.0	1.3	3.7	17.0

Appendix E.3 *continued*

Name	April 2009							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	1.2	1.4	1.3	0.8	0.6	0.8	0.6	6.7
Longfin sanddab		0.1	1.6	0.2	0.7		0.8	3.4
California scorpionfish				0.8		1.7	0.7	3.2
Roughback sculpin	0.2	0.4	0.1	0.5	0.7	0.3	0.9	3.1
Hornyhead turbot	0.5	0.8	0.7	0.2		0.1	0.6	2.9
California lizardfish	0.2	0.1	0.1	0.2	0.4	0.5	0.8	2.3
Longspine combfish		0.1		0.9	0.1	0.1	1.0	2.2
California skate			1.0	0.9				1.9
Yellowchin sculpin			0.8	0.3	0.1		0.7	1.9
California halibut		1.7						1.7
Fantail sole			1.0				0.6	1.6
English sole	0.5		0.6	0.2		0.1	0.1	1.5
Pacific pompano					0.7			0.7
Plainfin midshipman				0.1	0.1	0.1	0.1	0.4
California tonguefish		0.1	0.1				0.1	0.3
Pink seaperch			0.1		0.1	0.1		0.3
Unidentified rockfish					0.1		0.1	0.2
Bay pipefish			0.1					0.1
Northern anchovy					0.1			0.1
Pygmy poacher			0.1					0.1
Unidentified sea bass							0.1	0.1
Specklefin midshipman				0.1				0.1
Quarter Total	2.6	4.7	7.6	5.2	3.7	3.8	7.2	34.8

Appendix E.3 *continued*

Name	July 2009							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Speckled sanddab	1.1	1.5	0.9	0.6	0.6	0.9	0.9	6.5
Longfin sanddab		1.1		0.2	2.0	0.8	1.4	5.5
California lizardfish	0.4	0.7	0.6	0.6	0.6	0.6	0.9	4.4
Yellowchin sculpin		0.4	0.8	0.1	0.5	0.7	0.7	3.2
Hornyhead turbot	0.4	0.2	0.9	0.1	0.1	0.3	0.9	2.9
Roughback sculpin	0.1	0.3	0.2	0.1	0.4	0.5	0.2	1.8
California scorpionfish			0.2	0.4	0.7			1.3
California halibut		0.1				0.9		1.0
California skate	0.2						0.7	0.9
Plainfin midshipman		0.1	0.2		0.1	0.4		0.8
California tonguefish		0.1	0.1	0.1	0.1	0.1	0.1	0.6
Fantail sole				0.1		0.4		0.5
English sole	0.1		0.1		0.1	0.1		0.4
Longspine combfish					0.1		0.1	0.2
Pygmy poacher			0.1				0.1	0.2
Spotted cuskeel			0.1				0.1	0.2
Bigmouth sole							0.1	0.1
Pacific sanddab						0.1		0.1
Quarter Total	2.3	4.5	4.2	2.3	5.3	5.8	6.2	30.6

Appendix E.3 *continued*

Name	October 2009							Species Biomass by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
California lizardfish	0.5	0.3	2.5	1.1	2.9	0.6	0.2	8.1
California scorpionfish	0.3	1.4	0.8	0.8			1.5	4.8
Speckled sanddab	0.5	0.6	0.4	0.7	0.2	0.2	0.1	2.7
Hornyhead turbot	0.2	0.3	0.3	0.6	0.1	0.3	0.4	2.2
Yellowchin sculpin	0.1	0.1	0.2	0.1	0.2	0.6	0.1	1.4
Longfin sanddab		0.1		0.1	0.5	0.2	0.1	1.0
Roughback sculpin		0.1	0.1	0.1	0.1	0.4	0.1	0.9
California tonguefish				0.1	0.1	0.1	0.1	0.4
Plainfin midshipman					0.1	0.1	0.2	0.4
Fantail sole	0.2		0.1					0.3
Bigmouth sole			0.1	0.1				0.2
Longspine combfish						0.1	0.1	0.2
Pygmy poacher			0.1			0.1		0.2
White croaker							0.2	0.2
California skate						0.1		0.1
Quarter Total	1.8	2.9	4.6	3.7	4.2	2.8	3.1	23.1
Annual Total	**9.0**	**13.9**	**17.9**	**15.6**	**15.2**	**13.7**	**20.2**	**105.5**

Appendix E.4

Summary of the species that distinguish between each cluster group according to SIMPER analyses (i.e., average dissimilarity ≥ 1.5). Values are average abundance for each group being compared (i.e., Group "X" vs Group "Y") and the average dissimilarity between groups for each species.

Species	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups F & C	Group F	Group C	
speckled sanddab	10.15	4.80	18.08
Cluster Groups F & E	Group F	Group E	
California tonguefish	0.43	1.80	3.55
English sole	0.33	1.54	3.05
longfin sanddab	0.14	4.06	8.90
Cluster Groups C & E	Group C	Group E	
speckled sanddab	4.80	7.74	8.07
California tonguefish	0.60	1.80	3.72
English sole	0.38	1.54	3.11
longfin sanddab	0.38	4.06	9.21
Cluster Groups F & A	Group F	Group A	
speckled sanddab	10.15	4.69	19.68
hornyhead turbot	1.55	0.00	5.53
California lizardfish	1.45	3.74	10.04
fantail sole	0.20	1.00	2.97
Cluster Groups C & A	Group C	Group A	
speckled sanddab	4.80	4.69	4.48
fantail sole	0.27	1.00	3.69
spotted turbot	1.47	1.00	2.92
hornyhead turbot	1.72	0.00	7.07
Cluster Groups E & A	Group E	Group A	
speckled sanddab	7.74	4.69	8.38
longfin sanddab	4.06	0.00	10.80
hornyhead turbot	2.31	0.00	6.44
California lizardfish	1.55	3.74	6.72
English sole	1.54	0.00	4.08
spotted turbot	0.64	1.00	2.63
Cluster Groups F & H	Group F	Group H	
yellowchin sculpin	0.08	4.69	8.49
Cluster Groups C & H	Group C	Group H	
speckled sanddab	4.80	11.88	15.56
California lizardfish	0.63	3.89	6.81
yellowchin sculpin	0.00	4.69	9.28
roughback sculpin	0.00	2.69	5.42

Appendix E.4 *continued*

Species	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups E & H	Group E	Group H	
speckled sanddab	7.74	11.88	7.52
California tonguefish	1.80	1.01	2.42
Cluster Groups A & H	Group A	Group H	
speckled sanddab	4.69	11.88	16.65
hornyhead turbot	0.00	1.89	4.32
yellowchin sculpin	0.00	4.69	9.85
roughback sculpin	0.00	2.69	5.75
Cluster Groups F & G	Group F	Group G	
speckled sanddab	10.15	7.45	5.44
hornyhead turbot	1.45	14.54	26.13
California tonguefish	0.43	1.50	2.27
longfin sanddab	0.14	2.00	3.84
Cluster Groups C & G	Group C	Group G	
speckled sanddab	4.80	7.45	5.85
spotted turbot	1.47	0.00	3.12
hornyhead turbot	0.63	14.54	29.81
Cluster Groups E & G	Group E	Group G	
California tonguefish	1.80	1.50	2.06
hornyhead turbot	1.55	14.54	22.40
Cluster Groups A & G	Group A	Group G	
speckled sanddab	4.69	7.45	6.29
California lizardfish	3.74	14.54	24.63
spotted turbot	1.00	0.00	2.28
fantail sole	1.00	0.00	2.28
hornyhead turbot	0.00	1.87	4.27
California tonguefish	0.00	1.50	3.35
Cluster Groups H & G	Group H	Group G	
speckled sanddab	11.88	7.45	6.65
hornyhead turbot	3.89	14.54	16.22
Cluster Groups F & D	Group F	Group D	
speckled sanddab	10.15	3.28	18.97
longfin sanddab	0.14	3.42	9.12
Cluster Groups C & D	Group C	Group D	
longfin sanddab	0.38	3.42	9.47

Appendix E.4 *continued*

Species	Average Abundance		Average Dissimilarity
	Group "X"	Group "Y"	
Cluster Groups E & D	Group E	Group D	
speckled sanddab	7.74	3.28	10.04
California tonguefish	1.80	1.14	3.00
Cluster Groups A & D	Group A	Group D	
California lizardfish	3.74	4.06	7.74
longfin sanddab	0.00	3.42	11.52
hornyhead turbot	0.00	1.58	5.34
Cluster Groups H & D	Group H	Group D	
speckled sanddab	11.88	3.28	16.52
yellowchin sculpin	4.69	0.51	7.61
roughback sculpin	2.69	0.00	4.81
Cluster Groups G & D	Group G	Group D	
California lizardfish	14.54	4.06	20.09
speckled sanddab	7.45	3.28	7.98
Cluster Groups F & B	Group F	Group B	
speckled sanddab	10.15	2.83	26.99
hornyhead turbot	1.55	1.00	3.52
California scorpionfish	0.39	1.73	5.42
California skate	0.26	1.00	2.89
fantail sole	0.20	1.00	3.02
longfin sanddab	0.14	1.00	3.43
Cluster Groups C & B	Group C	Group B	
speckled sanddab	4.80	2.83	7.88
hornyhead turbot	1.72	1.00	3.74
spotted turbot	1.47	0.00	6.32
fantail sole	0.27	1.00	3.77
Cluster Groups E & B	Group E	Group B	
speckled sanddab	7.74	2.83	13.96
hornyhead turbot	2.31	1.00	3.59
English sole	1.54	0.00	4.13
California skate	0.00	1.00	2.94
Cluster Groups H & B	Group H	Group B	
speckled sanddab	11.88	2.83	21.18
yellowchin sculpin	4.69	0.00	9.95
roughback sculpin	2.69	0.00	5.81
longfin sanddab	2.32	1.00	3.82

Appendix E.4 *continued*

Species	Average Abundance		Average Dissimilarity
	Group "X"	**Group "Y"**	
Cluster Groups H & B (*continued*)	Group H	Group B	
California scorpionfish	0.78	1.73	2.45
fantail sole	0.33	1.00	1.67
California skate	0.12	1.00	2.12
Cluster Groups G & B	Group G	Group B	
California lizardfish	14.54	1.41	30.24
speckled sanddab	7.45	2.83	10.64
California scorpionfish	0.50	1.73	2.77
California skate	0.00	1.00	2.30
fantail sole	0.00	1.00	2.30
Cluster Groups D & B	Group D	Group B	
longfin sanddab	3.42	1.00	8.27
hornyhead turbot	1.58	1.00	1.99
fantail sole	0.91	1.00	2.15
California scorpionfish	0.13	1.73	5.41
California skate	0.13	1.00	3.00

Appendix E.5

List of megabenthic invertebrate taxa captured during 2009 at SBOO stations. Data are number of individuals (*n*). Taxonomic arrangement from SCAMIT 2008.

Taxon/ Species					*n*
CNIDARIA					
	ANTHOZOA				
		ALCYONACEA			
			Plexauridae		
				Thesea sp B	2
		PENNATULACEA			
			Virgulariidae		
				Acanthoptilum sp	1
MOLLUSCA					
	GASTROPODA				
			Calliostomatidae		
				Calliostoma annulatum	1
				Calliostoma gloriosum	2
				Calliostoma tricolor	1
				Calliostoma turbinum	1
			Turbinidae		
				Megastraea turbanica	2
		HYPSOGASTROPODA			
			Bursidae		
				Crossata californica	3
			Buccinidae		
				Kelletia kelletii	8
			Columbellidae		
				Amphissa undata	1
			Nassariidae		
				Caesia perpinguis	5
			Muricidae		
				Pteropurpura festiva	3
			Conidae		
				Conus californicus	1
			Turridae		
				Megasurcula carpenteriana	2
		OPISTHOBRANCHIA			
			Philinidae		
				Philine auriformis	21
			Aglajidae		
				Aglaja ocelligera	2
			Pleurobranchidae		
				Pleurobranchaea californica	1
			Onchidorididae		
				Acanthodoris brunnea	31
				Acanthodoris rhodoceras	7
			Arminidae		
				Armina californica	2

Appendix E.5 *continued*

Taxon/ Species					*n*
			Dendronotidae		
				Dendronotus iris	
			Tethyidae		
				Melibe leonina	6
			Flabellinidae		
				Flabellina iodinea	8
	CEPHALOPODA				
		OCTOPODA			
			Octopodidae		
				Octopus rubescens	10
ANNELIDA					
	POLYCHAETA				
		ACICULATA			
			Aphroditidae		
				Aphrodita armifera	6
				Aphrodita refulgida	1
			Polynoidae		
				Halosydna latior	3
				Harmothoe imbricata complex	1
ARTHROPODA					
	MALACOSTRACA				
		STOMATOPODA			
			Hemisquillidae		
				Hemisquilla californiensis	10
		ISOPODA			
			Cymothoidae		
				Elthusa vulgaris	8
		DECAPODA			
			Sicyoniidae		
				Sicyonia ingentis	12
				Sicyonia penicillata	2
			Hippolytidae		
				Heptacarpus fuscimaculatus	8
				Heptacarpus palpator	4
				Heptacarpus stimpsoni	33
				Lysmata californica	1
				Spirontocaris prionota	1
			Pandalidae		
				Pandalus danae	6
			Crangonidae		
				Crangon alba	3
				Crangon nigromaculata	50
			Paguridae		
				Orthopagurus minimus	32
				Pagurus spilocarpus	4
			Calappidae		
				Platymera gaudichaudii	14
			Leucosiidae		
				Randallia ornata	3

Appendix E.5 *continued*

Taxon/ Species					*n*
			Epialtidae		
				Loxorhynchus grandis	5
			Inachidae		
				Podochela hemphillii	4
			Inachoididae		
				Pyromaia tuberculata	25
			Parthenopidae		
				Heterocrypta occidentalis	13
			Cancridae		
				Metacarcinus anthonyi	1
				Metacarcinus gracilis	2
				Romaleon antennarius	1
				Romaleon jordani	1
			Portunidae		
				Portunus xantusii	2
			Pinnotheridae		
				Pinnixa franciscana	1
ECHINODERMATA					
	ASTEROIDEA				
		PAXILLOSIDA			
			Luidiidae		
				Luidia asthenosoma	1
			Astropectinidae		
				Astropecten verrilli	331
		FORCIPULATIDA			
			Asteriidae		
				Pisaster brevispinus	28
	OPHIUROIDEA				
		OPHIURIDA			
			Ophiotricidae		
				Ophiothrix spiculata	157
			Ophiuridae		
				Ophiura luetkenii	78
	ECHINOIDEA				
		TEMNOPLEUROIDA			
			Toxopneustidae		
				Lytechinus pictus	11
		CLYPEASTEROIDA			
			Dendrasteridae		
				Dendraster terminalis	67

Appendix E.6

Summary of total abundance by species and station for megabenthic invertebrates at the SBOO stations during 2009.

	January 2009							
Name	**SD15**	**SD16**	**SD17**	**SD18**	**SD19**	**SD20**	**SD21**	**Species Abundance by Survey**
Ophiothrix spiculata	1						100	101
Heptacarpus stimpsoni	17							17
Astropecten verrilli	7	6	1					14
Crangon nigromaculata		1			4		8	13
Heptacarpus fuscimaculatus	8							8
Hemisquilla californiensis			1	1			3	5
Pandalus danae	5							5
Pyromaia tuberculata		1		2	1	1		5
Elthusa vulgaris			2		2			4
Pisaster brevispinus		1				1	2	4
Lytechinus pictus			1	2				3
Heptacarpus palpator	2							2
Platymera gaudichaudii				2				2
Acanthoptilum sp	1							1
Armina californica	1							1
Calliostoma turbinum	1							1
Dendraster terminalis	1							1
Harmothoe imbricata complex							1	1
Kelletia kelletii						1		1
Loxorhynchus grandis							1	1
Lysmata californica	1							1
Metacarcinus anthonyi					1			1
Octopus rubescens							1	1
Pagurus spilocarpus							1	1
Portunus xantusii							1	1
Randallia ornata		1						1
Romaleon jordani				1				1
Sicyonia ingentis				1				1
Spirontocaris prionota	1							1
Quarter Total	46	10	5	9	8	3	118	199

Appendix E.6 *continued*

Name	April 2009							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Astropecten verrilli	53	9	5	15	14	34	1	131
Dendraster terminalis	50	1	4				1	56
Ophiothrix spiculata			2				49	51
Heptacarpus stimpsoni					1		15	16
Pyromaia tuberculata			1				13	14
Sicyonia ingentis				3			7	10
Crangon nigromaculata					2		6	8
Pisaster brevispinus		1			4		3	8
Philine auriformis					1		6	7
Platymera gaudichaudii	1		4			1		6
Hemisquilla californiensis				1		2	1	4
Podochela hemphillii			2	1				3
Calliostoma gloriosum							2	2
Dendronotus iris			2					2
Flabellina iodinea			1	1				2
Heptacarpus palpator							2	2
Thesea sp B	1	1						2
Acanthodoris brunnea			1					1
Aglaja ocelligera					1			1
Armina californica	1							1
Cancer antennarius			1					1
Crangon alba	1							1
Crossata californica				1				1
Elthusa vulgaris					1			1
Loxorhynchus grandis							1	1
Lytechinus pictus				1				1
Megastraea turbanica		1						1
Octopus rubescens			1					1
Pagurus spilocarpus	1							1
Pinnixa franciscana		1						1
Pleurobranchaea californica				1				1
Portunus xantusii	1							1
Randallia ornata							1	1
Quarter Total	109	14	24	24	24	37	108	340

Appendix E.6 *continued*

Name	July 2009 SD15	SD16	SD17	SD18	SD19	SD20	SD21	Species Abundance by Survey
Ophiura luetkenii	72							72
Astropecten verrilli		3		1	6	1	6	17
Pisaster brevispinus		1			2		6	9
Acanthodoris brunnea			5	1	1			7
Crangon nigromaculata					3		4	7
Acanthodoris rhodoceras			3				3	6
Kelletia kelletii			1	2	1		2	6
Melibe leonina					6			6
Octopus rubescens	1		1		1	2	1	6
Platymera gaudichaudii		1		2	1	2		6
Pyromaia tuberculata	1	1	1				2	5
Dendraster terminalis	3							3
Elthusa vulgaris				1		1	1	3
Ophiothrix spiculata	3							3
Crangon alba	2							2
Flabellina iodinea							2	2
Heterocrypta occidentalis				1			1	2
Metacarcinus gracilis		1				1		2
Pteropurpura festiva				1			1	2
Aglaja ocelligera			1					1
Crossata californica					1			1
Dendronotus iris			1					1
Hemisquilla californiensis		1						1
Loxorhynchus grandis							1	1
Luidia asthenosoma		1						1
Lytechinus pictus				1				1
Megastraea turbanica	1							1
Megasurcula carpenteriana							1	1
Pagurus spilocarpus	1							1
Philine auriformis							1	1
Sicyonia ingentis							1	1
Sicyonia penicillata				1				1
Quarter Total	84	9	13	11	22	7	33	179

Appendix E.6 *continued*

Name	October 2009							Species Abundance by Survey
	SD15	SD16	SD17	SD18	SD19	SD20	SD21	
Astropecten verrilli	122	9	20	7	9		2	169
Orthopagurus minimus				30	2			32
Acanthodoris brunnea		2	6	12	2	1		23
Crangon nigromaculata	2			1	4	15		22
Philine auriformis			1	12				13
Heterocrypta occidentalis			2	6	1	1	1	11
Dendraster terminalis	3		1	3				7
Pisaster brevispinus		1			2	1	3	7
Aphrodita armifera			1	5				6
Lytechinus pictus	1		1	4				6
Ophiura luetkenii				3	3			6
Nassarius perpinguis			2	2	1			5
Flabellina iodinea				4				4
Halosydna latior			1	2				3
Loxorhynchus grandis				2				2
Octopus rubescens					2			2
Ophiothrix spiculata				1	1			2
Acanthodoris rhodoceras							1	1
Amphissa undata							1	1
Aphrodita refulgida				1				1
Calliostoma annulatum		1						1
Calliostoma tricolor				1				1
Conus californicus						1		1
Crossata californica				1				1
Dendronotus iris						1		1
Kelletia kelletii						1		1
Megasurcula carpenteriana				1				1
Pagurus spilocarpus	1							1
Pandalus danae						1		1
Podochela hemphillii		1						1
Pteropurpura festiva							1	1
Pyromaia tuberculata					1			1
Randallia ornata				1				1
Sicyonia penicllata							1	1
Quarter Total	129	14	35	99	28	22	10	337
Annual Total	**368**	**47**	**77**	**143**	**82**	**69**	**269**	**1055**

Appendix F

Supporting Data

2009 SBOO Stations

Bioaccumulation of Contaminants in Fish Tissues

Appendix F.1

Lengths and weights of fishes used for each composite (Comp) sample for the SBOO monitoring program during April and October 2009. Data are summarized as number of individuals (*n*), minimum (Min), maximum (Max), and mean values.

				Length (cm, size class)			Weight (g)		
Station	**Comp**	**Species**	***n***	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
April 2009									
RF3	1	Brown rockfish	3	14	25	19	78	435	210
RF3	2	Brown rockfish	3	15	23	19	78	296	180
RF3	3	Mixed rockfish	4	14	22	18	50	266	147
RF4	1	Ca. scorpionfish	3	25	27	26	412	661	569
RF4	2	Ca. scorpionfish	3	27	32	29	653	907	781
RF4	3	Ca. scorpionfish	3	27	30	28	634	1070	800
SD15	1	English sole	3	15	26	21	57	273	165
SD15	2	Hornyhead turbot	6	16	25	20	99	225	170
SD15	3	(no sample)	—	—	—	—	—	—	—
SD16	1	Longfin sanddab	11	13	16	14	46	91	59
SD16	2	Hornyhead turbot	3	13	20	16	55	202	120
SD16	3	(no sample)	—	—	—	—	—	—	—
SD17	1	Longfin sanddab	7	13	17	15	47	95	70
SD17	2	Longfin sanddab	7	13	17	15	34	115	68
SD17	3	Longfin sanddab	12	12	60	17	14	59	47
SD18	1	Longfin sanddab	7	14	18	16	46	132	88
SD18	2	Longfin sanddab	10	13	17	15	51	107	81
SD18	3	Longfin sanddab	13	13	16	14	40	79	56
SD19	1	Longfin sanddab	5	13	16	14	48	66	57
SD19	2	Hornyhead turbot	3	10	19	15	18	161	93
SD19	3	(no sample)	—	—	—	—	—	—	—
SD20	1	(no sample)	—	—	—	—	—	—	—
SD20	2	(no sample)	—	—	—	—	—	—	—
SD20	3	(no sample)	—	—	—	—	—	—	—
SD21	1	Longfin sanddab	11	12	15	14	40	66	52
SD21	2	Longfin sanddab	13	12	16	13	40	81	51
SD21	3	Hornyhead turbot	5	17	21	19	134	238	175

Appendix F.1 *continued*

Station	Comp	Species	*n*	Length (cm, size class) Min	Max	Mean	Weight (g) Min	Max	Mean
October 2009									
RF3	1	Brown rockfish	3	22	24	23	277	364	315
RF3	2	Brown rockfish	3	18	32	23	150	843	405
RF3	3	Mixed rockfish	4	16	27	20	96	537	243
RF4	1	Ca. scorpionfish	3	26	28	27	562	652	607
RF4	2	Ca. scorpionfish	3	28	30	29	678	794	723
RF4	3	Ca. scorpionfish	3	24	30	26	636	817	726
SD15	1	Hornyhead turbot	7	12	16	13	34	113	71
SD15	2	(no sample)	—	—	—	—	—	—	—
SD15	3	(no sample)	—	—	—	—	—	—	—
SD16	1	Hornyhead turbot	4	12	21	17	45	216	125
SD16	2	Longfin sanddab	6	12	17	15	38	106	68
SD16	3	Longfin sanddab	8	11	14	13	30	60	44
SD17	1	Hornyhead turbot	3	17	19	18	139	159	146
SD17	2	Ca. scorpionfish	3	23	27	25	339	490	404
SD17	3	Hornyhead turbot	4	14	17	16	71	120	97
SD18	1	Hornyhead turbot	7	14	18	16	67	149	99
SD18	2	Hornyhead turbot	6	13	19	17	63	182	126
SD18	3	Ca. scorpionfish	4	18	24	21	104	404	285
SD19	1	Longfin sanddab	6	14	16	15	45	95	68
SD19	2	Longfin sanddab	10	13	14	14	36	60	45
SD19	3	Longfin sanddab	11	12	14	13	38	57	45
SD20	1	Longfin sanddab	8	13	16	15	41	70	55
SD20	2	Longfin sanddab	12	12	15	14	33	64	41
SD20	3	Hornyhead turbot	6	13	19	15	51	176	80
SD21	1	Hornyhead turbot	6	13	22	16	57	240	114
SD21	2	Hornyhead turbot	5	14	18	16	62	161	116
SD21	3	Ca. scorpionfish	3	23	24	24	367	419	390

Appendix F.2

Constituents and method detection limits for fish tissue samples analyzed for the SBOO monitoring program during April and October 2009.

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Metals (ppm)					
Aluminum (Al)	3	3	Lead (Pb)	0.2	0.2
Antimony (Sb)	0.2	0.2	Manganese (Mn)	0.1	0.1
Arsenic (As)	0.24	0.24	Mercury (Hg)	0.03	0.03
Barium (Ba)	0.03	0.03	Nickel (Ni)	0.2	0.2
Beryllium (Be)	0.006	0.006	Selenium (Se)	0.06	0.06
Cadmium (Cd)	0.06	0.06	Silver (Ag)	0.05	0.05
Chromium (Cr)	0.1	0.1	Thallium (Tl)	0.4	0.4
Copper (Cu)	0.1	0.1	Tin (Sn)	0.2	0.2
Iron (Fe)	2	2	Zinc (Zn)	0.15	0.15
Chlorinated Pesticides (ppb)					
HCH					
HCH, Alpha isomer	24.7	2.47	HCH, Delta isomer	4.53	0.45
HCH, Beta isomer	4.68	0.47	HCH, Gamma isomer	63.4	6.34
Total Chlordane					
Alpha (cis) Chlordane	4.56	0.46	Heptachlor epoxide	3.89	0.39
Cis Nonachlor	4.7	0.47	Oxychlordane	7.77	0.78
Gamma (trans) Chlordane	2.59	0.26	Trans Nonachlor	2.58	0.26
Heptachlor	3.82	0.38			
Total DDT					
o,p-DDD	2.02	0.2	p,p-DDE	2.08	0.21
o,p-DDE	2.79	0.28	p,-p-DDMU	3.29	0.33
o,p-DDT	1.62	0.16	p,p-DDT	2.69	0.27
p,p-DDD	3.36	0.34			
Miscellaneous Pesticides					
Aldrin	88.1	8.81	Hexachlorobenzene (HCB)	1.63	0.13
Alpha Endosulfan	118	11.8	Mirex	1.49	0.15

Appendix F.2 *continued*

Parameter	MDL Liver	MDL Muscle	Parameter	MDL Liver	MDL Muscle
Polychlorinated Biphenyls Congeners (PCBs) (ppb)					
PCB 18	2.86	0.29	PCB 126	1.52	0.15
PCB 28	2.47	0.28	PCB 128	1.23	0.12
PCB 37	2.77	0.25	PCB 138	1.73	0.17
PCB 44	3.65	0.36	PCB 149	2.34	0.23
PCB 49	5.02	0.50	PCB 151	1.86	0.19
PCB 52	5.32	0.53	PCB 153/168	2.54	0.25
PCB 66	2.81	0.28	PCB 156	0.64	0.06
PCB 70	2.49	0.25	PCB 157	2.88	0.29
PCB 74	3.10	0.31	PCB 158	2.72	0.27
PCB 77	2.01	0.20	PCB 167	1.63	0.16
PCB 81	3.56	0.36	PCB 169	2.76	0.28
PCB 87	3.01	0.30	PCB 170	1.23	0.12
PCB 99	3.05	0.30	PCB 177	1.91	0.19
PCB 101	4.34	0.43	PCB 180	2.58	0.26
PCB 105	2.29	0.23	PCB 183	1.55	0.15
PCB 110	2.50	0.25	PCB 187	2.50	0.25
PCB 114	3.15	0.31	PCB 189	1.78	0.18
PCB 118	2.06	0.21	PCB 194	1.14	0.11
PCB 119	2.39	0.24	PCB 201	2.88	0.29
PCB 123	2.64	0.26	PCB 206	1.28	0.13
Polycyclic Aromatic Hydrocarbons (PAHs) (ppb)					
1-methylnaphthalene	17.4	23.3	Benzo[G,H,I]perylene	27.2	59.5
1-methylphenanthrene	27.9	26.4	Benzo[K]fluoranthene	32.0	37.3
2,3,5-trimethylnaphthalene	21.7	21.6	Biphenyl	38.0	19.9
2,6-dimethylnaphthalene	21.7	19.5	Chrysene	18.1	23.0
2-methylnaphthalene	35.8	13.2	Dibenzo(A,H)anthracene	37.6	40.3
3,4-benzo(B)fluoranthene	30.2	26.8	Fluoranthene	19.9	12.9
Acenaphthene	28.9	11.3	Fluorene	27.3	11.4
Acenaphthylene	24.7	9.1	Indeno(1,2,3-CD)pyrene	25.6	46.5
Anthracene	25.3	8.4	Naphthalene	34.2	17.4
Benzo[A]anthracene	47.3	15.9	Perylene	18.5	50.9
Benzo[A]pyrene	42.9	18.3	Phenanthrene	11.6	12.9
Benzo[e]pyrene	41.8	40.6	Pyrene	9.1	16.6

Appendix F.3

Summary of constituents that make up total DDT, total chlordane, and total PCB in each composite sample (Comp) collected as part of the SBOO monitoring program during April and October 2009.

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	RF3	1	Brown rockfish	Muscle	DDT	p,p-DDE	1.8	µg/kg
2009-2	RF3	1	Brown rockfish	Muscle	PCB	PCB 153/168	0.5	µg/kg
2009-2	RF3	2	Brown rockfish	Muscle	DDT	p,p-DDE	5.7	µg/kg
2009-2	RF3	2	Brown rockfish	Muscle	PCB	PCB 153/168	0.6	µg/kg
2009-2	RF3	3	Mixed rockfish	Muscle	DDT	p,p-DDE	3.7	µg/kg
2009-2	RF3	3	Mixed rockfish	Muscle	PCB	PCB 99	0.3	µg/kg
2009-2	RF3	3	Mixed rockfish	Muscle	PCB	PCB 153/168	0.6	µg/kg
2009-2	RF4	1	Ca. scorpionfish	Muscle	DDT	p,p-DDE	1.9	µg/kg
2009-2	RF4	2	Ca. scorpionfish	Muscle	DDT	p,p-DDE	4.4	µg/kg
2009-2	RF4	2	Ca. scorpionfish	Muscle	PCB	PCB 153/168	0.4	µg/kg
2009-2	RF4	3	Ca. scorpionfish	Muscle	DDT	p,p-DDE	2.25	µg/kg
2009-2	RF4	3	Ca. scorpionfish	Muscle	PCB	PCB 153/168	0.35	µg/kg
2009-2	SD15	1	English sole	Liver	DDT	p,p-DDE	26	µg/kg
2009-2	SD15	1	English sole	Liver	PCB	PCB 99	2.6	µg/kg
2009-2	SD15	1	English sole	Liver	PCB	PCB 101	4.4	µg/kg
2009-2	SD15	1	English sole	Liver	PCB	PCB 138	3	µg/kg
2009-2	SD15	1	English sole	Liver	PCB	PCB 153/168	5.9	µg/kg
2009-2	SD15	1	English sole	Liver	PCB	PCB 187	2.8	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	DDT	p,p-DDE	100	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	4.6	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	PCB	PCB 99	3.3	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	PCB	PCB 101	2.8	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	PCB	PCB 118	2.3	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	PCB	PCB 138	4	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	PCB	PCB 153/168	11	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	PCB	PCB 180	4	µg/kg
2009-2	SD15	2	Hornyhead turbot	Liver	PCB	PCB 187	3.6	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	DDT	o,p-DDE	14	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDD	7.1	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDE	650	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	24	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	DDT	p,p-DDT	11	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 28	1.7	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 49	4.3	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 52	7.8	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 66	5.9	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 70	1.8	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 74	3.9	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 99	47	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 101	24	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 105	12	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 110	13	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 118	56	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 123	5.2	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 128	14	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 138	72	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 149	15	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 151	9.8	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 153/168	130	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 156	11	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 157	3.2	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 158	4.8	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 167	4.4	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 170	21	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 177	9.5	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 180	51	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 183	19	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 187	60	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 194	18	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 201	17	µg/kg
2009-2	SD16	1	Longfin sanddab	Liver	PCB	PCB 206	21	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	DDT	p,p-DDE	110	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	7.9	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 99	4.3	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 101	3.7	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 118	4.3	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 138	7.5	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 153/168	12	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 180	5.6	µg/kg
2009-2	SD16	2	Hornyhead turbot	Liver	PCB	PCB 187	6	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	DDT	o,p-DDE	14	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	DDT	p,p-DDD	8.7	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD17	1	Longfin sanddab	Liver	DDT	p,p-DDE	540	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	23	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 49	2.6	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 52	4.2	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 66	4.1	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 70	1.9	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 74	2.2	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 99	19	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 101	12	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 105	5.7	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 110	6.3	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 118	23	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 128	7.4	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 138	37	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 149	6.9	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 151	6.4	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 153/168	62	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 156	4.1	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 167	3.1	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 170	13	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 177	5.7	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 180	30	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 183	7.3	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 187	26	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 194	9.7	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 201	8.8	µg/kg
2009-2	SD17	1	Longfin sanddab	Liver	PCB	PCB 206	7.3	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	DDT	o,p-DDE	13	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	DDT	p,p-DDD	7.95	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	DDT	p,p-DDE	625	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	26	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	DDT	p,p-DDT	8.9	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 28	1.2	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 52	3.9	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 66	3.85	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 70	1.5	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 74	2.9	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 99	31	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 101	14	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 105	8.7	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 110	9.2	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 118	42.5	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 128	14	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 138	72	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 149	10.5	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 151	11.5	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 153/168	120	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 156	8.45	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 158	6.2	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 167	4.95	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 170	21	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 177	7.35	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 180	48	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 183	13.5	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 187	43	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 194	14.5	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 201	12	µg/kg
2009-2	SD17	2	Longfin sanddab	Liver	PCB	PCB 206	9.3	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	DDT	o,p-DDE	14	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	DDT	p,p-DDD	13	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	DDT	p,p-DDE	890	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	26	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	DDT	p,p-DDT	12	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 28	1.8	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 49	8.2	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 52	13	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 66	8.2	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 70	3.5	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 74	4.6	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 99	54	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 101	46	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 105	15	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 110	25	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 118	65	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 123	8.8	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 128	21	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 138	99	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 149	24	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 151	14	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 153/168	160	µg/kg

Appendix F.3 *continued*

YR-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 156	13	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 158	8.9	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 167	5.9	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 170	25	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 177	12	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 180	60	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 183	18	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 187	61	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 194	19	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 201	16	µg/kg
2009-2	SD17	3	Longfin sanddab	Liver	PCB	PCB 206	14	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	DDT	o,p-DDE	14	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDD	15	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	DDT	p,p-DDE	630	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	29	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 66	5.3	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 70	2.4	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 74	2.7	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 99	16	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 101	10	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 110	6.5	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 118	22	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 128	6.4	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 138	33	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 149	9.6	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 153/168	56	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 180	21	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 183	6	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 187	22	µg/kg
2009-2	SD18	1	Longfin sanddab	Liver	PCB	PCB 194	7.7	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	DDT	o,p-DDE	13	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	DDT	p,p-DDE	760	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	23	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 28	2.4	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 52	5	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 66	5.7	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 70	2.4	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 74	5.3	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 99	26	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 101	17	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 105	8.4	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 110	5.9	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 118	43	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 128	11	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 138	57	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 149	12	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 151	6.9	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 153/168	100	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 156	6.1	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 170	20	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 180	42	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 183	12	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 187	40	µg/kg
2009-2	SD18	2	Longfin sanddab	Liver	PCB	PCB 194	10	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	DDT	o,p-DDE	16	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	DDT	p,p-DDE	850	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	27	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 66	3.8	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 70	2.8	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 74	3.7	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 99	26	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 101	16	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 105	6.7	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 110	6.5	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 118	33	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 128	12	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 138	56	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 153/168	96	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 156	9.3	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 170	21	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 180	43	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 183	12	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 187	38	µg/kg
2009-2	SD18	3	Longfin sanddab	Liver	PCB	PCB 194	13	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	DDT	o,p-DDE	16	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDD	14	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDE	1100	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	33	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDT	21	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 28	1.5	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 49	2.5	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 52	6.4	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 66	5.3	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 70	2.1	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 74	4.7	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 99	42	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 101	19	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 105	14	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 110	9	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 118	63	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 123	5.7	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 128	17	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 138	97	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 149	13	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 151	11	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 153/168	170	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 156	11	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 157	2.3	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 158	7.8	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 167	6.3	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 170	26	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 177	11	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 180	63	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 183	18	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 187	61	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 194	20	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 201	18	µg/kg
2009-2	SD19	1	Longfin sanddab	Liver	PCB	PCB 206	13	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	DDT	p,p-DDE	140	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	5.7	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 49	1.3	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 52	2.1	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 66	1.2	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 70	0.8	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 74	0.9	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 99	4.7	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 101	3.5	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 118	4.5	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 138	7.2	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 149	2.1	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 151	1.8	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 153/168	12	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 170	3.5	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 180	4.1	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 183	2.1	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 187	5.9	µg/kg
2009-2	SD19	2	Hornyhead turbot	Liver	PCB	PCB 194	1.6	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	DDT	o,p-DDE	12	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	DDT	p,p-DDD	13	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	DDT	p,p-DDE	720	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	24	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	DDT	p,p-DDT	10	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 28	2.9	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 49	3.3	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 52	6.3	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 66	6.9	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 70	2.1	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 74	4	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 99	37	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 101	23	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 105	14	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 110	8.6	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 118	55	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 123	4.9	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 128	21	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 138	110	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 149	16	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 151	12	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 153/168	160	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 156	11	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 157	3.4	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 158	8.9	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 167	6.6	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 170	28	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 177	11	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 180	60	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 183	18	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 187	63	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 194	19	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 201	18	µg/kg
2009-2	SD21	1	Longfin sanddab	Liver	PCB	PCB 206	14	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	DDT	o,p-DDE	12	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	DDT	p,p-DDD	14	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	DDT	p,p-DDE	750	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	25	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	DDT	p,p-DDT	11	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 28	2.5	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 49	3.3	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 52	7.7	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 66	6.7	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 70	2.6	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 74	4.6	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 99	42	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 101	25	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 105	16	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 110	16	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 118	59	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 123	5.9	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 128	19	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 138	100	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 149	19	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 151	12	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 153/168	160	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 156	11	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 157	2.5	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 158	8.5	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 167	6.1	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 170	24	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 177	13	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 180	60	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 183	17	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 187	59	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 194	19	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 201	18	µg/kg
2009-2	SD21	2	Longfin sanddab	Liver	PCB	PCB 206	14	µg/kg
2009-2	SD21	3	Hornyhead turbot	Liver	DDT	p,p-DDE	54	µg/kg
2009-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 118	3.45	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 138	6	µg/kg
2009-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 153/168	9.25	µg/kg
2009-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 180	3.6	µg/kg
2009-2	SD21	3	Hornyhead turbot	Liver	PCB	PCB 187	4.85	µg/kg
2009-4	RF3	1	Brown rockfish	Muscle	DDT	p,p-DDE	1.8	µg/kg
2009-4	RF3	1	Brown rockfish	Muscle	PCB	PCB 153/168	0.2	µg/kg
2009-4	RF3	2	Brown rockfish	Muscle	DDT	p,p-DDE	2.7	µg/kg
2009-4	RF3	2	Brown rockfish	Muscle	PCB	PCB 99	0.4	µg/kg
2009-4	RF3	2	Brown rockfish	Muscle	PCB	PCB 101	0.4	µg/kg
2009-4	RF3	2	Brown rockfish	Muscle	PCB	PCB 138	0.4	µg/kg
2009-4	RF3	2	Brown rockfish	Muscle	PCB	PCB 153/168	0.5	µg/kg
2009-4	RF3	3	Mixed rockfish	Muscle	DDT	p,p-DDE	2.3	µg/kg
2009-4	RF3	3	Mixed rockfish	Muscle	PCB	PCB 138	0.2	µg/kg
2009-4	RF3	3	Mixed rockfish	Muscle	PCB	PCB 153/168	0.5	µg/kg
2009-4	RF4	1	Ca. scorpionfish	Muscle	DDT	p,p-DDE	2.3	µg/kg
2009-4	RF4	1	Ca. scorpionfish	Muscle	PCB	PCB 153/168	0.3	µg/kg
2009-4	RF4	2	Ca. scorpionfish	Muscle	DDT	p,p-DDE	8	µg/kg
2009-4	RF4	2	Ca. scorpionfish	Muscle	PCB	PCB 99	0.4	µg/kg
2009-4	RF4	2	Ca. scorpionfish	Muscle	PCB	PCB 101	0.4	µg/kg
2009-4	RF4	2	Ca. scorpionfish	Muscle	PCB	PCB 118	0.4	µg/kg
2009-4	RF4	2	Ca. scorpionfish	Muscle	PCB	PCB 138	0.7	µg/kg
2009-4	RF4	2	Ca. scorpionfish	Muscle	PCB	PCB 153/168	0.9	µg/kg
2009-4	RF4	2	Ca. scorpionfish	Muscle	PCB	PCB 187	0.3	µg/kg
2009-4	RF4	3	Ca. scorpionfish	Muscle	DDT	p,p-DDE	4.4	µg/kg
2009-4	RF4	3	Ca. scorpionfish	Muscle	PCB	PCB 138	0.3	µg/kg
2009-4	RF4	3	Ca. scorpionfish	Muscle	PCB	PCB 153/168	0.5	µg/kg
2009-4	SD15	1	Hornyhead turbot	Liver	DDT	p,p-DDE	46	µg/kg
2009-4	SD15	1	Hornyhead turbot	Liver	PCB	PCB 138	1.9	µg/kg
2009-4	SD15	1	Hornyhead turbot	Liver	PCB	PCB 153/168	6.3	µg/kg
2009-4	SD15	1	Hornyhead turbot	Liver	PCB	PCB 187	4.9	µg/kg
2009-4	SD16	1	Hornyhead turbot	Liver	DDT	p,p-DDE	40	µg/kg
2009-4	SD16	1	Hornyhead turbot	Liver	PCB	PCB 138	2.9	µg/kg
2009-4	SD16	1	Hornyhead turbot	Liver	PCB	PCB 153/168	4.7	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD16	2	Longfin sanddab	Liver	DDT	o,p-DDE	5.6	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	DDT	p,p-DDD	4.6	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	DDT	p,p-DDE	220	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	8	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	DDT	p,p-DDT	3.9	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 66	1.4	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 99	7.3	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 105	2.5	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 118	8	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 128	3	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 138	16	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 149	4.7	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 153/168	28	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 170	4.8	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 180	10	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 187	12	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 194	3.3	µg/kg
2009-4	SD16	2	Longfin sanddab	Liver	PCB	PCB 206	2.4	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	DDT	o,p-DDE	8.1	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	DDT	p,p-DDD	6	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	DDT	p,p-DDE	590	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	16	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	DDT	p,p-DDT	9.3	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 28	1.6	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 52	2.8	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 66	2.8	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 70	1.3	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 74	2.3	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 99	21	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 101	9.6	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 105	6.9	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 110	4	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 118	28	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 128	7.1	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 138	53	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 149	9.5	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 151	8.6	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 153/168	97	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 156	4.4	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 158	4.6	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 167	2.8	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 170	15	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 177	7.5	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 180	37	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 183	13	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 187	42	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 194	12	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 201	12	µg/kg
2009-4	SD16	3	Longfin sanddab	Liver	PCB	PCB 206	6.7	µg/kg
2009-4	SD17	1	Hornyhead turbot	Liver	DDT	p,p-DDE	62	µg/kg
2009-4	SD17	1	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.7	µg/kg
2009-4	SD17	1	Hornyhead turbot	Liver	PCB	PCB 138	4.1	µg/kg
2009-4	SD17	1	Hornyhead turbot	Liver	PCB	PCB 153/168	5.7	µg/kg
2009-4	SD17	1	Hornyhead turbot	Liver	PCB	PCB 180	3.2	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	Chlordane	Trans Nonachlor	14	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	DDT	p,p-DDD	8.2	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	DDT	p,p-DDE	700	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	DDT	p,-p-DDMU	11	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 28	1.4	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 44	2.4	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 49	4.5	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 52	6.1	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 66	4	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 70	1.8	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 74	3.1	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 87	4.8	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 99	23	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 101	29	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 105	7.7	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 110	13	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 118	29	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 128	8.6	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 138	49	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 149	9.7	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 151	11	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 153/168	79	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 170	13	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 177	7.7	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 180	31	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 183	11	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 187	33	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 194	7.9	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 201	8	µg/kg
2009-4	SD17	2	Ca. scorpionfish	Liver	PCB	PCB 206	5	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	Chlordane	Alpha (cis) Chlordane	11	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	Chlordane	Gamma (trans) Chlordane	9.3	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	DDT	p,p-DDD	11	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	DDT	p,p-DDE	170	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	4.9	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	DDT	p,p-DDT	7.3	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 66	1	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 74	1	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 99	4	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 101	3.5	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 118	3.2	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 138	6	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 149	3	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 151	1.2	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 153/168	9.3	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 180	4	µg/kg
2009-4	SD17	3	Hornyhead turbot	Liver	PCB	PCB 187	6.1	µg/kg
2009-4	SD18	1	Hornyhead turbot	Liver	DDT	p,p-DDE	49	µg/kg
2009-4	SD18	1	Hornyhead turbot	Liver	PCB	PCB 101	3.7	µg/kg
2009-4	SD18	1	Hornyhead turbot	Liver	PCB	PCB 138	6.1	µg/kg
2009-4	SD18	1	Hornyhead turbot	Liver	PCB	PCB 153/168	9.2	µg/kg
2009-4	SD18	1	Hornyhead turbot	Liver	PCB	PCB 180	5	µg/kg
2009-4	SD18	1	Hornyhead turbot	Liver	PCB	PCB 187	4.2	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	DDT	p,p-DDE	88	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	3.2	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	PCB	PCB 99	3	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	PCB	PCB 118	3	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	PCB	PCB 138	6.5	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	PCB	PCB 153/168	7.2	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	PCB	PCB 180	4.5	µg/kg
2009-4	SD18	2	Hornyhead turbot	Liver	PCB	PCB 187	3.9	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD18	3	Ca. scorpionfish	Liver	DDT	p,p-DDD	7.85	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	DDT	p,p-DDE	950	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	DDT	p,-p-DDMU	7.35	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 49	3.8	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 52	5.1	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 66	5.75	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 70	1.2	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 74	3.3	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 87	7.8	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 99	27.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 101	26.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 105	10.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 110	14.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 118	41	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 128	11	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 138	58	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 149	12	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 151	12.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 153/168	99	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 156	6.9	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 158	4.85	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 167	3.65	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 170	14.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 177	9.3	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 180	34.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 183	12	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 187	36.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 194	8.7	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 201	10.5	µg/kg
2009-4	SD18	3	Ca. scorpionfish	Liver	PCB	PCB 206	4.9	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	DDT	o,p-DDE	5	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDD	6.3	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	DDT	p,p-DDE	360	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	10	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 28	1.8	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 52	2.8	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 66	2.8	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 70	0.9	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 74	1.8	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 99	11	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 101	6.9	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 110	3.6	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 118	15	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 128	5.1	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 138	26	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 149	7.6	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 151	4.8	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 153/168	41	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 170	5.2	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 180	14	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 183	6.3	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 187	23	µg/kg
2009-4	SD19	1	Longfin sanddab	Liver	PCB	PCB 194	4	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	DDT	o,p-DDE	4.3	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	DDT	p,p-DDE	220	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	DDT	p,-p-DDMU	7.1	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 66	1.6	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 74	1.1	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 99	8.2	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 105	2.3	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 118	7.3	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 138	15	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 149	3.8	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 151	3.9	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 153/168	26	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 170	5.5	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 180	12	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 183	5.1	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 187	16	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 194	3.9	µg/kg
2009-4	SD19	2	Longfin sanddab	Liver	PCB	PCB 201	4.1	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	DDT	o,p-DDE	7.2	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	DDT	p,p-DDD	8	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	DDT	p,p-DDE	630	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	DDT	p,-p-DDMU	12	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	DDT	p,p-DDT	7.8	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 28	0.9	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 66	2.6	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 70	2.1	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 74	2.6	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 99	21	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 101	8.8	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 105	5.7	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 118	23	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 128	6	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 138	43	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 149	4.1	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 151	8	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 153/168	73	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 156	4.5	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 167	3	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 170	11	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 177	8	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 180	26	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 183	9.7	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 187	35	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 194	8.5	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 201	9	µg/kg
2009-4	SD19	3	Longfin sanddab	Liver	PCB	PCB 206	5.9	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	DDT	o,p-DDE	8	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDD	6.7	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDE	670	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	DDT	p,-p-DDMU	17	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	DDT	p,p-DDT	7	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 28	1.1	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 49	3.1	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 52	3	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 66	3.4	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 70	0.8	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 74	2.7	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 99	29	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 101	11	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 105	7.8	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 110	6.4	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 118	33	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 128	8.4	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 138	57	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 149	6.9	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 151	10	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 153/168	85	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 156	5	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 167	3.6	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 170	14	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 177	6.7	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 180	37	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 183	13	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 187	37	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 194	9.2	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 201	9.4	µg/kg
2009-4	SD20	1	Longfin sanddab	Liver	PCB	PCB 206	4.6	µg/kg
2009-4	SD20	2	Longfin sanddab	Liver	DDT	p,p-DDE	27	µg/kg
2009-4	SD20	2	Longfin sanddab	Liver	PCB	PCB 153/168	2.4	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	DDT	o,p-DDE	35	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	DDT	p,p-DDD	12	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	DDT	p,p-DDE	2700	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	DDT	p,-p-DDMU	44	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	DDT	p,p-DDT	11	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 28	1.5	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 49	2.9	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 52	5.1	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 66	5.4	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 70	1.8	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 74	5.9	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 99	55	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 101	17	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 105	15	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 110	8.9	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 118	66	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 123	6.2	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 128	18	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 138	120	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 149	18	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 151	21	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 153/168	190	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 156	9.6	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 157	2.2	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 158	9.7	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 167	5.7	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 170	28	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 177	14	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 180	72	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 183	21	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 187	72	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 194	19	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 201	19	µg/kg
2009-4	SD20	3	Hornyhead turbot	Liver	PCB	PCB 206	12	µg/kg
2009-4	SD21	1	Hornyhead turbot	Liver	DDT	p,p-DDE	32	µg/kg
2009-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 138	5.2	µg/kg
2009-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 153/168	8.9	µg/kg
2009-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 180	4	µg/kg
2009-4	SD21	1	Hornyhead turbot	Liver	PCB	PCB 187	6	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	DDT	p,p-DDE	76	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	DDT	p,-p-DDMU	2.7	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 99	6.1	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 101	4.1	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 118	4.6	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 138	9.3	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 149	4.5	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 153/168	20	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 180	5.2	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 183	3.3	µg/kg
2009-4	SD21	2	Hornyhead turbot	Liver	PCB	PCB 187	8.9	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	Chlordane	Trans Nonachlor	15	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	DDT	o,p-DDE	6.95	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	DDT	p,p-DDD	13	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	DDT	p,p-DDE	960	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	DDT	p,-p-DDMU	16	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	DDT	p,p-DDT	7.9	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 49	5.65	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 52	7.55	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 66	6.25	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 70	1.3	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 74	3.2	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 87	7.7	µg/kg

Appendix F.3 *continued*

Yr-Qtr	Station	Comp	Species	Tissue	Class	Parameter	Value	Units
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 99	31	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 101	39	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 105	10.4	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 110	15	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 118	41	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 128	10	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 138	60.5	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 149	18	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 151	12.5	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 153/168	99	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 156	5.35	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 158	4.8	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 167	3.3	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 170	15.5	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 177	11	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 180	39	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 183	13.5	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 187	47	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 194	9.25	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 201	11	µg/kg
2009-4	SD21	3	Ca. scorpionfish	Liver	PCB	PCB 206	5.45	µg/kg

Appendix G

Supporting Data

2009 Regional Stations

Sediment Conditions

Appendix G.1

Summary of the constituents that make up total HCH, total chlordane, total DDT, total PCB, and total PAH in each sediment sample collected as part of the 2009 regional survey.

Station	Class	Constituent	Value	Units
2651	PCB	PCB 153/168	43	ppt
2651	DDT	p,p-DDE	730	ppt
2656	DDT	p,p-DDE	420	ppt
2656	DDT	p,p-DDT	170	ppt
2659	DDT	p,p-DDE	320	ppt
2661	DDT	p,p-DDT	320	ppt
2662	DDT	p,p-DDE	450	ppt
2663	DDT	p,p-DDE	330	ppt
2664	PCB	PCB 180	330	ppt
2664	DDT	p,p-DDE	320	ppt
2667	DDT	p,p-DDE	450	ppt
2668	PCB	PCB 101	400	ppt
2668	PCB	PCB 110	83	ppt
2668	PCB	PCB 118	160	ppt
2668	PCB	PCB 138	390	ppt
2668	PCB	PCB 149	110	ppt
2668	PCB	PCB 153/168	100	ppt
2668	PCB	PCB 187	60	ppt
2668	DDT	p,p-DDE	920	ppt
2673	DDT	p,p-DDE	390	ppt
2674	PCB	PCB 110	130	ppt
2674	PCB	PCB 118	160	ppt
2674	DDT	p,p-DDD	95	ppt
2674	DDT	p,p-DDE	750	ppt
2674	DDT	p,p-DDT	300	ppt
2675	PAH	Benzo[A]anthracene	20.1	ppb
2675	PCB	PCB 49	270	ppt
2675	PCB	PCB 110	82	ppt
2675	PCB	PCB 138	250	ppt
2675	PCB	PCB 149	300	ppt
2675	PCB	PCB 153/168	240	ppt
2675	PCB	PCB 177	220	ppt
2675	PCB	PCB 180	970	ppt
2675	DDT	p,p-DDD	170	ppt
2675	DDT	p,p-DDE	660	ppt
2675	DDT	p,p-DDT	520	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
2676	PAH	3,4-benzo[B]fluoranthene	25.1	ppb
2676	PAH	Anthracene	27.2	ppb
2676	PAH	Benzo[A]anthracene	24.7	ppb
2676	PAH	Chrysene	48.0	ppb
2676	PAH	Fluoranthene	23.2	ppb
2676	PAH	Pyrene	39.7	ppb
2676	PCB	PCB 49	76	ppt
2676	PCB	PCB 52	1500	ppt
2676	PCB	PCB 66	76	ppt
2676	PCB	PCB 70	230	ppt
2676	PCB	PCB 99	150	ppt
2676	PCB	PCB 101	760	ppt
2676	PCB	PCB 118	470	ppt
2676	PCB	PCB 128	210	ppt
2676	PCB	PCB 138	460	ppt
2676	PCB	PCB 149	430	ppt
2676	PCB	PCB 153/168	270	ppt
2676	PCB	PCB 156	48	ppt
2676	PCB	PCB 177	87	ppt
2676	PCB	PCB 180	1100	ppt
2679	DDT	p,p-DDE	120	ppt
2681	PCB	PCB 49	460	ppt
2681	PCB	PCB 52	360	ppt
2681	PCB	PCB 66	240	ppt
2681	PCB	PCB 70	240	ppt
2681	PCB	PCB 99	240	ppt
2681	PCB	PCB 101	840	ppt
2681	PCB	PCB 105	120	ppt
2681	PCB	PCB 110	590	ppt
2681	PCB	PCB 118	440	ppt
2681	PCB	PCB 128	150	ppt
2681	PCB	PCB 138	510	ppt
2681	PCB	PCB 149	410	ppt
2681	PCB	PCB 153/168	270	ppt
2681	PCB	PCB 156	56	ppt
2681	PCB	PCB 158	52	ppt
2681	PCB	PCB 177	190	ppt
2681	PCB	PCB 180	690	ppt
2681	DDT	o,p-DDD	77	ppt
2681	DDT	p,p-DDD	210	ppt
2681	DDT	p,p-DDE	820	ppt

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
2682	PAH	3,4-benzo[B]fluoranthene	27.3	ppb
2682	PAH	Benzo[A]anthracene	25.0	ppb
2682	PAH	Benzo[A]pyrene	22.9	ppb
2682	PAH	Chrysene	46.4	ppb
2682	PAH	Fluoranthene	22.7	ppb
2682	PAH	Pyrene	20.7	ppb
2682	PCB	PCB 28	620	ppt
2682	PCB	PCB 44	1300	ppt
2682	PCB	PCB 49	1600	ppt
2682	PCB	PCB 52	2200	ppt
2682	PCB	PCB 66	2000	ppt
2682	PCB	PCB 70	1800	ppt
2682	PCB	PCB 74	770	ppt
2682	PCB	PCB 87	1100	ppt
2682	PCB	PCB 99	1000	ppt
2682	PCB	PCB 101	2900	ppt
2682	PCB	PCB 105	710	ppt
2682	PCB	PCB 110	2400	ppt
2682	PCB	PCB 118	1700	ppt
2682	PCB	PCB 119	310	ppt
2682	PCB	PCB 123	150	ppt
2682	PCB	PCB 128	490	ppt
2682	PCB	PCB 138	6800	ppt
2682	PCB	PCB 149	1700	ppt
2682	PCB	PCB 151	610	ppt
2682	PCB	PCB 153/168	850	ppt
2682	PCB	PCB 156	200	ppt
2682	PCB	PCB 158	200	ppt
2682	PCB	PCB 167	130	ppt
2682	PCB	PCB 170	420	ppt
2682	PCB	PCB 177	360	ppt
2682	PCB	PCB 180	1400	ppt
2682	PCB	PCB 183	240	ppt
2682	PCB	PCB 187	410	ppt
2682	PCB	PCB 194	170	ppt
2682	PCB	PCB 201	190	ppt
2682	DDT	o,p-DDD	170	ppt
2682	DDT	p,p-DDD	580	ppt
2682	DDT	p,p-DDE	1200	ppt
2685	DDT	p,p-DDE	270	ppt
2688	DDT	p,p-DDE	140	ppt
2811	PAH	Chrysene [a]	50	ppb

Appendix G.1 *continued*

Station	Class	Constituent	Value	Units
2812	Chlordane	Alpha (cis) Chlordane	890	ppt
2812	Chlordane	Gamma (trans) Chlordane	870	ppt
2812	HCH	HCH, Beta isomer	1200	ppt
2812	HCH	HCH, Delta isomer	4000	ppt
2812	HCH	HCH, Gamma isomer	1500	ppt
2812	DDT	p,p-DDD	220	ppt
2812	DDT	p,p-DDE	770	ppt
2814	Chlordane	Alpha (cis) Chlordane	430	ppt
2814	Chlordane	Gamma (trans) Chlordane	900	ppt
2814	HCH	HCH, Beta isomer	800	ppt
2814	HCH	HCH, Delta isomer	2600	ppt
2814	DDT	p,p-DDD	170	ppt
2814	DDT	p,p-DDE	550	ppt
2815	PAH	Anthracene	21.5	ppb
2815	PAH	Chrysene [a]	42.1	ppb
2816	PAH	Chrysene [a]	45.9	ppb
2816	PCB	PCB 206	880	ppt

[a] Chrysene detections believed due to background chrysene contamination from internal standard. Likely not from chrysene present in the ocean sediment sample.

Appendix G.2

Summary of particle size parameters for the 2009 regional survey stations. SD = standard deviation; abbreviated observations are: Sh = shell hash; G = gravel; R = rock; Od = organic debris; Rrs = red relict sand; Mt = mud worm tubes; Cs = coarse sand; Ct = chaetopterid tubes; St = sand worm tubes.

	Station	Depth (m)	Mean (mm)	Mean (phi)	SD (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)	Visual Observations
Inner Shelf	2655	26	0.804	0.3	0.4	25.5	74.5	0.0	0.0	0.0	Sh, Rrs, Cs
	2657	21	0.119	3.1	0.6	0.0	91.1	8.8	0.1	8.9	
	2660	13	0.149	2.7	0.7	0.9	95.0	4.2	0.0	4.2	St
	2669	11	0.223	2.2	0.8	0.8	98.9	0.3	0.0	0.3	Sh, St
	2671	13	0.166	2.6	0.5	0.0	97.2	2.8	0.0	2.8	Sh, G, R
	2672	15	0.155	2.7	0.5	0.0	96.8	3.2	0.0	3.2	Sh, St
	2678	29	0.095	3.4	1.0	0.0	79.3	19.8	1.0	20.7	St
	2679	13	0.114	3.1	0.8	0.0	86.4	13.5	0.1	13.6	
	2683	24	0.109	3.2	0.8	0.0	89.4	10.2	0.4	10.5	
	2688	26	0.113	3.2	0.8	0.0	87.1	12.5	0.4	12.9	
	2689	14	0.106	3.2	0.8	0.0	84.9	15.0	0.1	15.1	
Mid-shelf	2653	59	0.050	4.3	1.9	0.0	54.1	40.8	5.1	45.9	Sh, G, R
	2656	78	0.042	4.6	1.6	0.0	44.0	52.4	3.6	56.0	
	2658	60	0.048	4.4	1.6	0.0	51.3	45.8	2.9	48.7	Sh
	2659	83	0.038	4.7	1.5	0.0	38.3	57.5	4.2	61.7	
	2661	64	0.047	4.4	1.6	0.0	50.8	46.4	2.8	49.2	Sh
	2664	60	0.051	4.3	1.6	0.0	55.4	41.8	2.8	44.6	
	2667	70	0.046	4.4	1.5	0.0	49.5	47.4	3.1	50.5	
	2673	51	0.060	4.1	1.5	0.0	65.1	32.2	2.6	34.9	Sh, Od
	2674	66	0.048	4.4	1.6	0.0	51.9	44.6	3.5	48.1	Sh, G
	2675	86	0.047	4.4	1.5	0.0	48.8	47.9	3.3	51.2	Sh, G, R, Cs
	2676	95	0.054	4.2	1.7	0.0	56.7	39.7	3.6	43.3	Sh, G, R, Cs
	2681	67	0.076	3.7	1.7	0.0	67.7	30.3	2.0	32.3	Sh, Od
	2682	84	0.055	4.2	1.7	0.0	58.3	38.0	3.7	41.7	Sh
	2686	43	0.468	1.1	1.1	10.3	85.3	4.4	0.0	4.4	Sh, Cs
	2687	43	0.436	1.2	0.7	7.8	91.3	0.9	0.0	0.9	Sh, Rrs, Cs
Outer Shelf	2651	163	0.044	4.5	1.8	0.0	48.4	47.0	4.7	51.6	Sh, G, Ct
	2662	147	0.048	4.4	1.7	0.0	56.2	40.0	3.9	43.8	Sh
	2663	128	0.071	3.8	0.8	4.1	53.1	42.8	0.0	42.8	Sh
	2665	177	0.037	4.7	1.6	0.0	39.3	56.8	3.9	60.7	
	2668	151	0.045	4.5	1.7	0.0	51.2	44.4	4.4	48.8	Sh, Cs
	2670	169	0.263	1.9	1.4	7.1	87.6	5.3	0.0	5.3	Sh, G, R, Cs
	2680	138	0.141	2.8	1.7	0.0	81.8	16.5	1.7	18.2	Sh, G, R, Cs
	2685	122	0.072	3.8	2.1	0.0	66.6	29.4	4.0	33.4	Sh, G
Upper Slope	2811	404	0.023	5.5	1.5	0.0	17.5	76.8	5.8	82.5	
	2812	357	0.032	5.0	1.7	0.0	32.3	62.4	5.3	67.7	Mt
	2813	257	0.033	4.9	1.8	0.0	35.3	59.6	5.1	64.7	Sh, Ct
	2814	413	0.046	4.5	1.8	0.0	50.6	45.7	3.7	49.4	
	2815	349	0.027	5.2	1.7	0.0	26.8	66.3	6.9	73.2	G, Mt
	2816	335	0.025	5.3	1.5	0.0	21.8	73.3	4.9	78.2	

Appendix G.3

Summary of particle size parameters for the 1999 regional survey stations. Due to differences in particle size analyses since 2003, the coarse and sand fractions cannot be estimated in a manner comparable to 2009 data. Visual observations are not available for these samples; SD = standard deviation; na = not available.

	Station	Depth (m)	Mean (mm)	Mean (phi)	SD (phi)	Coarse (%)	Sand (%)	Silt (%)	Clay (%)	Fines (%)
Inner Shelf	2655	27	0.660	0.6	1.0	na	na	0.0	0.0	0.0
	2657	19	0.117	3.1	0.6	na	na	7.4	0.4	7.8
	2660	12	0.144	2.8	0.4	na	na	3.7	0.0	3.7
	2669	11	0.467	1.1	0.6	na	na	0.0	0.0	0.0
	2671	12	0.233	2.1	0.6	na	na	1.0	0.0	1.0
	2672	15	0.330	1.6	0.7	na	na	0.3	0.0	0.3
	2678	30	0.102	3.3	0.9	na	na	15.8	1.1	16.9
	2679	12	0.095	3.4	1.1	na	na	20.4	0.5	20.9
	2683	23	0.109	3.2	0.6	na	na	6.8	0.4	7.2
	2688	25	0.125	3.0	0.6	na	na	7.5	0.2	7.7
	2689	13	0.134	2.9	0.8	na	na	11.7	0.4	12.1
Mid-shelf	2653	58	0.054	4.2	1.9	na	na	35.6	5.6	41.2
	2656	77	0.038	4.7	1.6	na	na	54.4	4.6	59.0
	2658	59	0.044	4.5	1.6	na	na	47.1	4.5	51.6
	2659	83	0.038	4.7	1.5	na	na	57.2	4.4	61.6
	2661	63	0.047	4.4	1.5	na	na	45.5	3.7	49.2
	2664	60	0.054	4.2	1.5	na	na	39.3	3.4	42.7
	2667	68	0.047	4.4	1.4	na	na	47.0	3.9	50.9
	2673	49	0.082	3.6	1.1	na	na	19.7	3.7	23.4
	2674	65	0.058	4.1	1.5	na	na	37.1	3.0	40.1
	2675	85	0.063	4.0	1.4	na	na	30.4	2.7	33.1
	2676	94	0.063	4.0	1.7	na	na	30.2	3.4	33.6
	2681	66	0.144	2.8	1.7	na	na	19.2	2.6	21.8
	2682	83	0.072	3.8	1.7	na	na	32.0	3.4	35.4
	2686	43	0.330	1.6	0.6	na	na	0.0	0.0	0.0
	2687	42	0.435	1.2	0.8	na	na	0.0	0.0	0.0
Outer Shelf	2651	152	0.036	4.8	1.7	na	na	45.5	6.6	52.1
	2662	146	0.054	4.2	1.6	na	na	35.3	4.3	39.6
	2663	130	0.051	4.3	1.7	na	na	36.5	4.5	41.0
	2665	180	0.031	5.0	1.7	na	na	57.7	8.3	66.0
	2668	149	0.038	4.7	1.7	na	na	48.9	4.9	53.8
	2670	168	0.250	2.0	1.5	na	na	10.5	1.6	12.1
	2680	138	0.500	1.0	0.5	na	na	0.9	0.0	0.9
	2685	121	0.102	3.3	2.4	na	na	23.7	5.3	29.0
	Minimum	11	0.031	0.6	0.4	na	na	0.0	0.0	0.0
	Maximum	180	0.660	5.0	2.4	na	na	57.7	8.3	66.0

Appendix G.4

Concentrations of contaminants in sediments from the 2009 regional stations. TN = total nitrogen; TOC = total organic carbon; HCH = hexachlorocyclohexane; HCB = hexachlorobenzene; nd = not detected; ERL = effects range low threshold value; ERM = effects range median threshold value; na = not available; see Appendix C.1 for MDLs and periodic table symbols. Values that exceed ERL or ERM values are in bold.

	Station	Depth (m)	Sulfides (ppm)	TN (% weight)	TOC (% weight)	HCH (ppt)	Chlordane (ppt)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)	tPAH (ppb)
Inner Shelf	2655	26	nd	0.065	0.753	nd	nd	nd	nd	nd	nd
	2657	21	3.56	0.020	0.294	nd	nd	nd	150	nd	nd
	2660	13	3.20	0.018	0.371	nd	nd	nd	nd	nd	nd
	2669	11	0.93	0.016	0.140	nd	nd	nd	nd	nd	nd
	2671	13	0.81	0.015	0.154	nd	nd	nd	nd	nd	nd
	2672	15	0.34	0.018	0.128	nd	nd	nd	160	nd	nd
	2678	29	17.10	0.032	0.288	nd	nd	nd	220	nd	nd
	2679	13	2.61	0.024	0.180	nd	nd	120	nd	nd	nd
	2683	24	nd	0.020	0.148	nd	nd	nd	nd	nd	nd
	2688	26	1.24	0.020	0.178	nd	nd	140	nd	nd	nd
	2689	14	1.03	0.018	0.165	nd	nd	nd	nd	nd	nd
Mid-shelf	2653	59	0.47	0.134	2.780	nd	nd	nd	240	nd	nd
	2656	78	0.48	0.080	0.929	nd	nd	590	nd	nd	nd
	2658	60	0.18	0.083	0.858	nd	nd	nd	400	nd	nd
	2659	83	0.41	0.087	0.984	nd	nd	320	310	nd	nd
	2661	64	0.75	0.062	0.721	nd	nd	320	nd	nd	nd
	2664	60	1.46	0.070	0.786	nd	nd	320	150	330	nd
	2667	70	2.96	0.071	0.857	nd	nd	450	260	nd	nd
	2673	51	1.74	0.057	0.639	nd	nd	390	410	nd	nd
	2674	66	0.37	0.073	0.850	nd	nd	1145	nd	290	nd
	2675	86	1.67	0.058	0.720	nd	nd	1350	290	2332	20.1
	2676	95	0.43	0.044	0.754	nd	nd	nd	780	5867	187.9
	2681	67	0.43	0.039	0.466	nd	nd	1107	150	5858	nd
	2682	84	2.43	0.052	0.656	nd	nd	**1950**	330	34730	165.0
	2686	43	0.17	0.014	0.099	nd	nd	nd	nd	nd	nd
	2687	43	nd	0.016	0.091	nd	nd	nd	nd	nd	nd
Outer Shelf	2651	163	33.40	0.107	1.290	nd	nd	730	320	43	nd
	2662	147	1.77	0.065	0.825	nd	nd	450	nd	nd	nd
	2663	128	1.16	0.070	2.260	nd	nd	330	nd	nd	nd
	2665	177	22.00	0.106	1.580	nd	nd	nd	nd	nd	nd
	2668	151	4.71	0.083	1.190	nd	nd	920	1400	1303	nd
	2670	169	1.54	0.026	1.460	nd	nd	nd	nd	nd	nd
	2680	138	1.34	0.069	8.820	nd	nd	nd	nd	nd	nd
	2685	122	0.23	0.087	8.030	nd	nd	270	nd	nd	nd
Upper Slope	2811	404	9.58	0.305	3.175	nd	nd	nd	460	nd	50.0
	2812	357	6.88	0.154	2.277	6700	1760	990	210	nd	nd
	2813	257	7.60	0.161	3.074	nd	nd	nd	nd	nd	nd
	2814	413	nd	0.165	2.907	3400	1330	720	nd	nd	nd
	2815	349	10.80	0.180	2.661	nd	nd	nd	nd	nd	63.6
	2816	335	10.30	0.247	3.110	nd	nd	nd	nd	880	45.9
		ERL:	na	na	na	na	na	1580	na	na	4022
		ERM:	na	na	na	na	na	46100	na	na	44792

Appendix G.4 *continued*

	Station	Depth (m)	Metals (ppm)								
			Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
Inner Shelf	2655	26	2310	0.50	**8.64**	20.5	0.02	0.09	9.7	1.5	7670
	2657	21	4210	nd	1.05	25.1	0.06	nd	7.0	1.3	4810
	2660	13	4520	nd	0.74	30.5	0.06	nd	7.8	1.1	6130
	2669	11	2520	nd	1.55	11.1	0.03	nd	4.8	0.8	3910
	2671	13	3160	nd	1.36	15.4	0.04	nd	6.5	1.0	5110
	2672	15	2970	0.33	2.36	15.6	0.04	nd	6.3	1.0	4970
	2678	29	8980	0.47	2.16	50.1	0.18	0.09	16.5	8.6	14000
	2679	13	6630	nd	2.16	31.7	0.10	0.10	10.9	3.9	7630
	2683	24	5020	nd	1.14	21.4	0.06	nd	8.4	6.6	5010
	2688	26	6530	nd	1.44	37.7	0.09	0.06	10.7	5.3	7210
	2689	14	8040	0.38	2.94	46.4	0.11	nd	14.0	3.0	10600
Mid-shelf	2653	59	10800	0.56	4.12	49.3	0.31	0.19	23.3	6.5	20300
	2656	78	11700	0.57	3.68	53.3	0.27	0.15	21.0	8.3	15300
	2658	60	10800	0.52	3.89	57.5	0.25	0.23	20.7	9.3	14600
	2659	83	14300	0.61	4.71	54.0	0.31	0.14	23.3	9.7	17000
	2661	64	12100	0.42	2.09	50.5	0.25	0.20	19.7	7.8	13900
	2664	60	10900	0.46	3.65	49.4	0.24	0.24	18.5	8.1	12800
	2667	70	12100	0.56	3.78	63.0	0.26	0.24	21.1	10.3	15600
	2673	51	9810	0.56	3.12	47.8	0.20	0.19	16.2	8.8	12700
	2674	66	10400	0.51	4.38	64.0	0.20	0.19	19.1	10.4	15000
	2675	86	10400	0.52	4.31	53.5	0.20	0.11	18.7	8.2	14000
	2676	95	8110	0.55	3.79	55.2	0.17	0.09	15.7	10.4	13400
	2681	67	4570	0.63	2.37	26.2	0.28	0.26	24.5	3.5	19200
	2682	84	9690	0.64	3.48	49.1	0.17	0.10	18.1	25.8	12500
	2686	43	1450	nd	3.81	4.1	0.03	nd	8.0	nd	6050
	2687	43	1490	nd	7.34	3.3	0.04	nd	10.5	nd	7400
Outer Shelf	2651	163	11600	0.50	4.44	69.0	0.33	0.51	21.5	9.5	17400
	2662	147	9210	0.51	2.07	32.5	0.21	0.18	16.3	6.2	10800
	2663	128	7340	0.41	2.75	31.2	0.22	0.26	15.6	6.3	11500
	2665	177	9380	0.52	2.69	48.2	0.26	0.23	20.8	10.4	13800
	2668	151	11600	nd	2.44	40.2	0.26	0.14	20.1	9.7	14200
	2670	169	5660	0.51	**9.02**	115.0	0.49	0.20	35.0	1.9	15900
	2680	138	5140	nd	4.50	33.4	0.07	0.06	9.3	2.7	6280
	2685	122	8320	0.54	3.39	30.2	0.28	0.20	24.7	5.5	19600
Upper Slope	2811	404	17700	nd	3.19	105.0	0.45	0.49	36.8	21.3	19600
	2812	357	10400	nd	2.81	71.8	0.33	0.40	27.3	14.5	14900
	2813	257	10800	nd	2.74	60.7	0.34	0.30	27.0	14.3	14700
	2814	413	13400	nd	7.76	80.8	0.42	0.41	68.2	13.2	27400
	2815	349	13800	nd	3.12	80.9	0.40	0.43	32.0	17.3	17300
	2816	335	18900	nd	3.95	94.8	0.48	0.43	36.9	21.7	20300
		ERL:	na	na	8.2	na	na	1.2	81	34	na
		ERM:	na	na	70	na	na	9.6	370	270	na

Appendix G.4 *continued*

	Station	Depth (m)	Metals (ppm)								
			Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Inner Shelf	2655	26	2.40	91.5	nd	2.0	nd	nd	nd	0.91	15.6
	2657	21	1.23	74.3	nd	1.8	nd	nd	nd	0.56	13.7
	2660	13	1.44	86.5	nd	2.0	nd	nd	nd	0.56	17.8
	2669	11	1.45	37.7	nd	1.2	nd	nd	nd	0.45	8.1
	2671	13	1.52	53.0	0.003	1.3	nd	nd	nd	0.53	9.4
	2672	15	2.14	51.2	0.008	1.3	nd	nd	nd	0.67	9.6
	2678	29	4.88	99.1	0.014	6.9	nd	nd	nd	1.26	33.1
	2679	13	2.68	72.9	0.004	4.0	nd	nd	nd	0.70	20.6
	2683	24	1.21	60.1	nd	2.2	nd	nd	nd	0.35	12.0
	2688	26	1.59	76.1	nd	3.5	nd	nd	nd	0.48	18.3
	2689	14	2.27	97.3	0.005	4.6	nd	nd	nd	0.52	23.2
Mid-shelf	2653	59	5.58	111.0	0.023	7.4	nd	nd	nd	1.47	46.1
	2656	78	5.79	121.0	0.033	8.7	nd	nd	nd	1.63	40.0
	2658	60	6.30	124.0	0.034	8.8	nd	nd	nd	1.35	43.0
	2659	83	6.03	132.0	0.028	10.3	nd	nd	nd	1.41	45.1
	2661	64	5.69	121.0	0.031	8.2	nd	nd	nd	1.36	38.9
	2664	60	5.31	116.0	0.043	7.7	0.27	nd	nd	1.38	37.1
	2667	70	6.20	129.0	0.043	9.5	nd	nd	nd	1.44	43.0
	2673	51	4.73	114.0	0.035	6.9	nd	nd	nd	1.18	35.2
	2674	66	6.75	124.0	0.080	9.0	nd	nd	nd	1.21	44.1
	2675	86	5.56	111.0	0.052	8.9	0.26	nd	nd	1.06	35.9
	2676	95	5.29	95.5	0.047	6.7	nd	nd	nd	0.90	38.2
	2681	67	4.08	29.8	0.032	6.1	nd	nd	nd	1.67	34.6
	2682	84	12.10	108.0	0.026	8.9	nd	nd	nd	1.67	81.8
	2686	43	1.85	19.8	nd	1.1	nd	nd	nd	nd	7.3
	2687	43	2.87	19.7	nd	1.0	nd	nd	nd	0.38	7.1
Outer Shelf	2651	163	5.94	139.0	0.038	9.3	nd	nd	nd	1.12	48.5
	2662	147	3.81	87.5	0.016	7.5	nd	nd	nd	0.90	29.8
	2663	128	3.79	72.8	0.015	6.6	0.24	nd	nd	0.86	29.9
	2665	177	4.87	103.0	0.040	11.2	0.37	nd	nd	1.07	38.6
	2668	151	4.29	101.0	0.045	9.5	0.25	nd	nd	1.06	37.2
	2670	169	2.21	26.2	0.014	4.2	0.36	nd	nd	0.59	23.2
	2680	138	1.79	59.2	0.014	3.0	0.41	nd	nd	0.42	16.8
	2685	122	4.63	55.3	0.029	8.6	0.32	nd	nd	0.75	38.1
Upper Slope	2811	404	8.03	168.0	0.062	**22.5**	1.37	nd	nd	1.36	66.0
	2812	357	6.27	123.0	0.041	14.9	0.81	nd	nd	1.05	48.6
	2813	257	6.17	111.0	0.037	15.1	1.05	nd	nd	1.13	45.9
	2814	413	5.12	77.6	0.024	15.5	1.24	nd	nd	0.91	52.2
	2815	349	6.98	143.0	0.049	18.2	0.55	nd	nd	1.14	55.6
	2816	335	8.23	171.0	0.064	**21.9**	1.25	nd	nd	1.49	65.5
		ERL:	46.7	na	0.15	20.9	na	1	na	na	150
		ERM:	218	na	0.71	51.6	na	3.7	na	na	410

Appendix G.5

Concentrations of contaminants in sediments from the 1999 regional stations. TN = total nitrogen; TOC = total organic carbon; HCH = hexachlorocyclohexane; HCB = hexachlorobenzene; nd = not detected; na = not analyzed; DR (%) = detection rate; Min = minimum value; Max = maximum value; MDL = method detection limit; see Appendix C.1 for periodic table symbols.

	Station	Depth (m)	Sulfides (ppm)	TN (%)	TOC (%)	HCH (ppt)	Chlordane (ppt)	tDDT (ppt)	HCB (ppt)	tPCB (ppt)	tPAH (ppb)
Inner Shelf	2655	27	0.59	0.022	0.111	nd	nd	nd	na	nd	nd
	2657	19	14.30	0.021	0.125	nd	nd	nd	na	nd	nd
	2660	12	2.68	0.016	0.079	nd	nd	nd	na	nd	nd
	2669	11	0.98	0.014	0.067	nd	nd	nd	na	nd	nd
	2671	12	1.13	0.012	0.048	nd	nd	nd	na	nd	nd
	2672	15	1.24	0.017	0.057	nd	nd	nd	na	nd	78.6
	2678	30	4.17	0.031	0.219	nd	nd	nd	na	nd	nd
	2679	12	23.70	0.020	0.122	nd	nd	nd	na	nd	nd
	2683	23	9.24	0.016	0.114	nd	nd	nd	na	nd	nd
	2688	25	6.88	0.022	0.143	nd	nd	nd	na	nd	nd
	2689	13	21.60	0.016	0.108	nd	nd	nd	na	nd	nd
Mid-shelf	2653	58	3.08	0.066	0.584	nd	nd	nd	na	nd	nd
	2656	77	2.46	0.080	0.757	nd	nd	nd	na	nd	nd
	2658	59	1.78	0.076	0.700	nd	nd	nd	na	nd	nd
	2659	83	2.46	0.085	0.773	nd	nd	nd	na	nd	nd
	2661	63	4.24	0.062	0.549	nd	nd	nd	na	nd	nd
	2664	60	1.62	0.062	0.576	nd	nd	nd	na	nd	nd
	2667	68	3.57	0.069	0.667	nd	nd	nd	na	nd	nd
	2673	49	7.77	0.062	0.498	nd	nd	nd	na	nd	nd
	2674	65	6.21	0.076	0.676	nd	nd	nd	na	nd	nd
	2675	85	3.35	0.072	0.680	nd	nd	nd	na	nd	nd
	2676	94	4.29	0.051	0.496	nd	nd	nd	na	nd	163.7
	2681	66	6.57	0.043	0.405	nd	nd	1000	na	nd	nd
	2682	83	14.20	0.058	0.554	nd	nd	2300	na	nd	183.8
	2686	43	0.25	0.011	0.026	nd	nd	nd	na	nd	nd
	2687	42	0.13	0.010	0.015	nd	nd	nd	na	nd	nd
Outer Shelf	2651	152	97.70	0.125	1.190	nd	nd	nd	na	nd	nd
	2662	146	3.64	0.070	0.635	nd	nd	nd	na	nd	nd
	2663	130	2.48	0.073	0.670	nd	nd	nd	na	nd	nd
	2665	180	81.90	0.117	1.130	nd	nd	nd	na	nd	nd
	2668	149	18.90	0.088	0.866	nd	nd	nd	na	nd	nd
	2670	168	2.51	0.037	0.325	nd	nd	nd	na	nd	nd
	2680	138	0.80	0.046	0.395	nd	nd	nd	na	nd	nd
	2685	121	5.63	0.083	0.660	nd	nd	nd	na	nd	nd
		DR (%)	100	100	100	0	0	6	na	0	9
		Min	0.13	0.010	0.015	nd	nd	nd	na	nd	nd
		Max	97.70	0.125	1.190	nd	nd	2300	na	nd	183.8
		MDL	0.05	0.005	0.01	1300	3800	940	na	9600	46

Appendix G.5 *continued*

	Station	Depth (m)	Metals (ppm) Al	Sb	As	Ba	Be	Cd	Cr	Cu	Fe
Inner Shelf	2655	27	1750	nd	4.02	na	nd	nd	7.1	nd	5130
	2657	19	4120	nd	0.76	na	nd	nd	6.3	10.4	4900
	2660	12	4160	nd	1.27	na	nd	nd	6.6	nd	6020
	2669	11	2430	nd	1.58	na	nd	nd	4.5	nd	3680
	2671	12	3620	nd	1.89	na	nd	nd	6.4	nd	5330
	2672	15	2740	nd	1.65	na	nd	nd	6.3	nd	4820
	2678	30	8380	nd	2.06	na	nd	0.96	10.6	3.6	7940
	2679	12	9120	nd	2.77	na	nd	nd	11.1	4.1	8970
	2683	23	5750	nd	1.61	na	nd	0.71	7.8	nd	5120
	2688	25	8010	nd	1.79	na	nd	0.99	9.9	2.5	6760
	2689	13	9870	nd	2.91	na	nd	nd	13.0	4.1	10500
Mid-shelf	2653	58	11400	nd	2.76	na	nd	nd	17.5	7.0	15200
	2656	77	15400	nd	5.05	na	nd	nd	21.7	9.3	17500
	2658	59	13900	nd	3.98	na	nd	nd	20.1	9.5	16200
	2659	83	14500	nd	4.17	na	nd	nd	20.0	13.2	16200
	2661	63	12000	nd	3.61	na	nd	nd	17.2	7.3	13300
	2664	60	13400	nd	4.08	na	nd	nd	18.6	8.9	14300
	2667	68	15300	nd	5.33	na	nd	nd	21.0	11.0	17100
	2673	49	12400	nd	3.91	na	nd	nd	16.4	9.5	14100
	2674	65	14300	2.85	4.06	na	nd	nd	21.1	15.1	17200
	2675	85	15900	nd	3.74	na	nd	nd	20.6	10.5	16600
	2676	94	12300	nd	3.16	na	nd	nd	16.9	16.6	15100
	2681	66	8710	nd	2.91	na	nd	nd	11.3	6.1	9520
	2682	83	10400	nd	3.13	na	nd	nd	15.4	30.6	12000
	2686	43	1350	nd	5.69	na	nd	0.97	6.8	nd	6250
	2687	42	1300	nd	6.40	na	nd	0.67	7.9	nd	6750
Outer Shelf	2651	152	21800	8.50	4.77	na	nd	nd	27.4	14.6	22300
	2662	146	10300	nd	3.00	na	nd	nd	15.6	11.4	12100
	2663	130	11500	nd	3.13	na	nd	nd	17.4	8.4	13800
	2665	180	19000	nd	3.13	na	nd	nd	26.7	14.1	18900
	2668	149	15900	5.80	3.56	na	nd	nd	21.8	18.1	16700
	2670	168	6500	nd	7.46	na	nd	nd	34.7	2.3	16000
	2680	138	6080	nd	5.83	na	nd	nd	24.9	4.0	20600
	2685	121	11200	6.10	4.32	na	nd	nd	25.7	9.0	21800
		DR (%)	100	12	100	na	0	15	100	76	100
		Min	1300	nd	0.76	na	nd	nd	4.5	nd	3680
		Max	21800	8.50	7.46	na	nd	0.99	34.7	30.6	22300
		MDL	5	5	0.32	na	0.2	0.5	3	2	3

Appendix G.5 *continued*

	Station	Depth (m)	Metals (ppm) Pb	Mn	Hg	Ni	Se	Ag	Tl	Sn	Zn
Inner Shelf	2655	27	nd	68.1	nd	nd	nd	nd	nd	nd	10.3
	2657	19	nd	74.2	nd	nd	nd	nd	nd	nd	12.5
	2660	12	nd	85.5	nd	nd	nd	nd	nd	nd	13.2
	2669	11	nd	nd	nd	nd	nd	nd	nd	nd	7.0
	2671	12	nd	60.2	nd	nd	nd	nd	nd	nd	9.0
	2672	15	nd	50.7	nd	nd	nd	nd	nd	nd	7.8
	2678	30	nd	86.9	nd	nd	nd	nd	nd	nd	23.3
	2679	12	nd	87.7	nd	11.2	nd	nd	nd	nd	19.7
	2683	23	nd	52.1	nd	18.8	nd	nd	nd	nd	10.5
	2688	25	nd	77.4	nd	nd	nd	nd	nd	nd	15.1
	2689	13	nd	99.6	nd	nd	nd	nd	nd	nd	23.7
Mid-shelf	2653	58	nd	107.0	nd	6.8	0.18	nd	nd	nd	30.4
	2656	77	6.10	140.0	nd	9.4	0.22	nd	nd	nd	37.4
	2658	59	nd	126.0	0.043	8.7	0.19	nd	nd	nd	41.8
	2659	83	8.90	126.0	0.048	8.9	0.23	nd	nd	nd	35.0
	2661	63	nd	118.0	0.041	7.6	0.18	nd	nd	nd	30.7
	2664	60	5.20	125.0	0.054	8.2	0.25	nd	nd	nd	34.3
	2667	68	6.40	140.0	0.052	10.4	0.27	nd	nd	nd	41.6
	2673	49	7.80	122.0	0.033	7.8	0.19	nd	nd	nd	33.3
	2674	65	5.50	136.0	0.019	10.0	0.22	nd	nd	nd	50.3
	2675	85	nd	131.0	0.057	10.1	0.25	nd	nd	nd	37.1
	2676	94	6.60	108.0	0.067	7.8	0.22	nd	nd	nd	34.1
	2681	66	nd	nd	nd	5.6	0.15	nd	nd	nd	20.5
	2682	83	9.20	90.3	0.024	7.5	0.18	nd	nd	nd	51.7
	2686	43	nd	17.8	nd	17.2	nd	nd	nd	nd	5.9
	2687	42	nd	20.3	nd	nd	nd	nd	nd	nd	5.0
Outer Shelf	2651	152	9.38	184.0	nd	12.3	0.37	nd	nd	nd	53.4
	2662	146	nd	87.0	0.020	7.6	0.29	nd	nd	nd	26.0
	2663	130	nd	91.8	0.020	7.9	0.30	nd	nd	nd	28.3
	2665	180	7.20	137.0	0.037	14.5	0.49	nd	nd	nd	44.1
	2668	149	nd	116.0	0.036	11.1	0.40	nd	nd	nd	37.6
	2670	168	nd	30.1	nd	5.3	0.33	nd	nd	nd	20.6
	2680	138	nd	28.4	nd	5.9	0.48	nd	nd	nd	26.6
	2685	121	nd	54.9	nd	9.1	0.43	nd	nd	nd	33.5
		DR (%)	29	94	41	71	62	0	0	0	100
		Min	nd	nd	nd	nd	nd	nd	nd	nd	5.0
		Max	9.38	184.0	0.067	18.8	0.49	nd	nd	nd	53.4
		MDL	5	0.48	0.03	3	0.11	3	10	12	4

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Appendix H

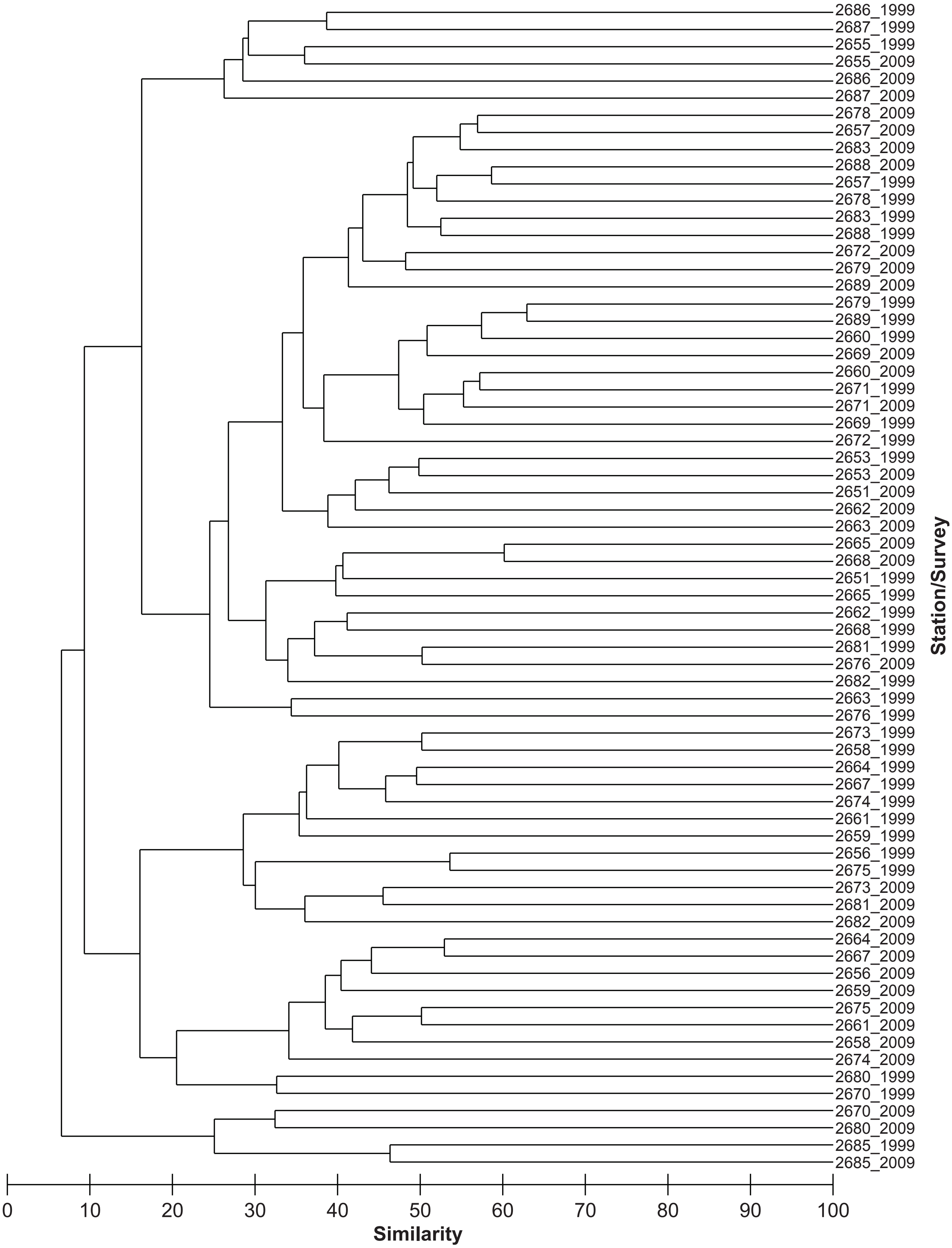
Supporting Data

2009 Regional Stations

Macrobenthic Communities

Appendix H.1

Dendrogram showing cluster analysis results of the macrofaunal abundance data for the 34 continental shelf depth (<200 m) stations sampled during the 2009 and 1999 regional surveys.



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Appendix H.2

All taxa composing cluster groups A–G from the 2009 surveys of SBOO benthic stations. Data are expressed as mean abundance per sample (no./0.1 m^2) and represent the most abundant taxa in each group. Values for the three most abundant species in each cluster group are in bold, (*n*) = number of station/survey entities per cluster group.

		Cluster Group						
Species/Taxa	Phyla	A (1)	B (6)	C (6)	D (5)	E (3)	F (6)	G (13)
Acidostoma hancocki	Arthropoda			0.2				
Acoetes pacifica	Annelida						0.2	
Acteocina cerealis	Mollusca				0.2	0.3	0.2	0.9
Acteocina culcitella	Mollusca		1.0	0.2				
Acteocina harpa	Mollusca		0.5					
Acteocina sp	Mollusca		0.2					
Actiniaria	Cnidaria	1.0	0.2					
Admete gracilior	Mollusca					0.3		
Adontorhina cyclia	Mollusca				0.2	1.0	4.7	3.8
Aglaja ocelligera	Mollusca			0.2				
Aglaophamus erectans	Annelida				0.2			
Aglaophamus verrilli	Annelida						0.3	1.2
Agnezia septentrionalis	Chordata			6.5				
Alvania rosana	Mollusca							0.8
Amaeana occidentalis	Annelida						0.3	0.6
Amage anops	Annelida						1.0	
Americhelidium shoemakeri	Arthropoda	1.0	1.2	0.2		0.3	0.2	
Americhelidium sp SD4	Arthropoda					0.3		
Ampelisca agassizi	Arthropoda		3.8	1.8		0.3		0.2
Ampelisca brachycladus	Arthropoda			0.2				
Ampelisca brevisimulata	Arthropoda			4.8		0.3	0.7	2.0
Ampelisca careyi	Arthropoda			0.3		5.0	1.2	1.6
Ampelisca cf *brevisimulata*	Arthropoda							0.9
Ampelisca cristata cristata	Arthropoda	3.0		2.7				
Ampelisca cristata microdentata	Arthropoda			3.2				
Ampelisca hancocki	Arthropoda					1.7	0.2	1.5
Ampelisca indentata	Arthropoda							2.0
Ampelisca pacifica	Arthropoda					1.3	0.7	3.5
Ampelisca pugetica	Arthropoda			1.7				1.5
Ampelisca romigi	Arthropoda							0.2
Ampelisca sp	Arthropoda			0.2			0.2	0.2
Ampelisca unsocalae	Arthropoda				0.8		0.2	
Ampelisciphotis podophthalma	Arthropoda							0.1
Ampharete finmarchica	Annelida							0.1
Ampharete labrops	Annelida		2.8	0.5				0.2
Ampharete sp	Annelida							0.2
Ampharetidae	Annelida			0.2	0.6	0.3		0.2
Ampharetidae sp SD1	Annelida					0.3		0.2
Amphichondrius granulatus	Echinodermata						0.7	0.1
Amphicteis mucronata	Annelida						0.2	
Amphicteis scaphobranchiata	Annelida			0.3			1.3	0.4
Amphideutopus oculatus	Arthropoda			0.7				
Amphiodia digitata	Echinodermata		0.5	2.2	0.4	7.3	1.8	
Amphiodia psara	Echinodermata			0.2				
Amphiodia sp	Echinodermata			1.0		3.7	0.5	8.5

Appendix H.2 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Amphiodia urtica	Echinodermata			2.0			3.2	66.9
Amphioplus sp A	Echinodermata			0.2				
Amphioplus strongyloplax	Echinodermata				1.6		0.2	
Amphipholis sp	Echinodermata					0.3	0.2	
Amphipholis squamata	Echinodermata			0.2				
Amphissa bicolor	Mollusca				0.4			
Amphissa undata	Mollusca			0.2				0.5
Amphiura arcystata	Echinodermata			0.2				0.5
Amphiuridae	Echinodermata		0.7	5.5	0.6	0.3	1.2	2.2
Amygdalum politum	Mollusca						0.3	
Anarthruridae	Arthropoda						0.2	
Anchicolurus occidentalis	Arthropoda		2.3					
Ancistrosyllis groenlandica	Annelida				0.4	0.3		
Anobothrus gracilis	Annelida						0.2	
Anonyx lilljeborgi	Arthropoda							0.1
Anotomastus gordiodes	Annelida			0.3				
Aonides sp SD1	Annelida	3.0						
Aoroides inermis	Arthropoda		0.2					
Aoroides intermedia	Arthropoda		0.3					
Aoroides sp	Arthropoda						0.2	
Aoroides sp A	Arthropoda					1.0		0.3
Aphelochaeta glandaria complex	Annelida					19.3	1.5	0.6
Aphelochaeta monilaris	Annelida		0.2		0.2	1.0	3.3	2.4
Aphelochaeta petersenae	Annelida							0.2
Aphelochaeta phillipsi	Annelida	1.0				2.0	1.0	
Aphelochaeta sp	Annelida		0.2			1.3	0.2	0.4
Aphelochaeta sp LA1	Annelida						0.3	0.5
Aphelochaeta sp SD13	Annelida				0.2	1.0		
Aphelochaeta tigrina	Annelida					2.0	0.7	0.2
Aphelochaeta williamsae	Annelida				0.2	0.3	0.2	0.2
Apionsoma misakianum	Sipuncula	20.0				0.3		
Apoprionospio pygmaea	Annelida		1.5	0.5				
Arachnanthus sp A	Cnidaria							0.1
Araphura breviaria	Arthropoda					0.3		0.1
Araphura cuspirostris	Arthropoda				0.2			
Araphura sp	Arthropoda						0.2	
Araphura sp SD1	Arthropoda					0.7		
Argissa hamatipes	Arthropoda		0.2		0.2	0.3		0.2
Aricidea (*Acmira*) *catherinae*	Annelida			0.2		3.3	0.5	0.5
Aricidea (*Acmira*) *cerrutii*	Annelida	1.0				1.0		
Aricidea (*Acmira*) *lopezi*	Annelida					2.7	0.3	1.1
Aricidea (*Acmira*) *rubra*	Annelida					0.7		
Aricidea (*Acmira*) *simplex*	Annelida			0.5			0.5	2.1
Aricidea (*Allia*) *antennata*	Annelida					1.0	0.2	0.3
Aricidea (*Allia*) *hartleyi*	Annelida			0.2				0.1
Aricidea (*Allia*) sp A	Annelida						0.8	0.5
Aricidea (*Allia*) sp SD1	Annelida			0.5				
Aricidea (*Aricidea*) sp SD1	Annelida			0.2				
Aricidea (*Aricidea*) *wassi*	Annelida			0.3		0.7		0.1

Appendix H.2 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Armandia brevis	Annelida		0.5					
Artacamella hancocki	Annelida			0.7		0.3	0.2	0.3
Aruga holmesi	Arthropoda							0.1
Aruga oculata	Arthropoda	2.0		0.2				1.2
Ascidiacea	Chordata			0.5				
Asteroidea	Echinodermata							0.2
Astropecten ornatissimus	Echinodermata					0.3	0.2	
Astropecten verrilli	Echinodermata							0.2
Axinopsida serricata	Mollusca					0.3	15.0	20.8
Axiothella sp	Annelida		0.2	0.8				
Balcis micans	Mollusca		0.2	0.2				
Bathymedon pumilus	Arthropoda				0.2			0.2
Bivalvia	Mollusca		0.3		0.6		0.2	
Brada pluribranchiata	Annelida							0.5
Brada villosa	Annelida							0.1
Branchiostoma californiense	Chordata	6.0						
Brisaster sp	Echinodermata				0.8			
Brissopsis pacifica	Echinodermata				0.8	0.7	0.3	
Bullomorpha sp A	Mollusca							0.1
Byblis millsi	Arthropoda			0.2				1.5
Caecognathia crenulatifrons	Arthropoda			1.5	0.4	1.3	0.2	1.6
Caecognathia sp SD1	Arthropoda					1.3		
Caesia fossatus	Mollusca		0.2					
Caesia perpinguis	Mollusca		0.2	0.5				
Callianax baetica	Mollusca	5.0	0.2	0.5				
Campylaspis canaliculata	Arthropoda							0.2
Campylaspis hartae	Arthropoda					1.0		
Campylaspis rubromaculata	Arthropoda			0.2				
Capitella teleta	Annelida							0.1
Caprella mendax	Arthropoda			0.3				0.3
Cardiomya pectinata	Mollusca							0.1
Carinoma mutabilis	Nemertea		3.7	1.5			0.2	0.1
Caulleriella sp	Annelida			0.2				
Cerapus tubularis complex	Arthropoda		0.5	0.2				
Cerebratulus californiensis	Nemertea			0.2				0.1
Ceriantharia	Cnidaria	1.0			0.2			
Chaetoderma nanulum	Mollusca				0.2			
Chaetoderma pacificum	Mollusca						1.2	0.2
Chaetozone corona	Annelida			0.2				
Chaetozone hartmanae	Annelida					0.3	2.2	2.6
Chaetozone sp	Annelida			0.3		15.3		
Chaetozone sp SD1	Annelida		0.2					
Chaetozone sp SD2	Annelida			0.2				
Chaetozone sp SD3	Annelida					0.7		
Chaetozone sp SD5	Annelida		1.3	0.2		12.0		
Chaetozone spinosa	Annelida							0.1
Chauliopleona dentata	Arthropoda					0.7		0.5
Chiridota sp	Echinodermata				1.0		0.5	1.2
Chloeia pinnata	Annelida					1.0		0.1

Appendix H.2 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Chone albocincta	Annelida		0.2					
Chone ecaudata	Annelida			0.2				0.1
Chone eiffelturris	Annelida		0.3					
Chone paramollis	Annelida							0.1
Chone sp	Annelida			0.3	1.2			
Chone sp B	Annelida			0.2		0.3		
Chone trilineata	Annelida					2.7		0.7
Chone veleronis	Annelida			1.2				0.1
Cirratulidae	Annelida			0.2	0.2		0.2	0.2
Cirratulus sp	Annelida	1.0				1.0		
Cirriformia sp	Annelida		0.3					
Cirrophorus branchiatus	Annelida						0.2	
Clymenella sp A	Annelida			0.2				
Clymenura gracilis	Annelida						0.7	1.9
Cnemidocarpa rhizopus	Chordata	4.0		0.2				
Compressidens stearnsii	Mollusca				2.8	1.0	0.7	0.4
Compsomyax subdiaphana	Mollusca			0.2				0.2
Cooperella subdiaphana	Mollusca		2.3	3.0				
Copepoda	Arthropoda				0.6			
Corymorpha bigelowi	Cnidaria							0.1
Cossura candida	Annelida						1.8	0.9
Cossura sp	Annelida			0.2			0.5	
Cossura sp A	Annelida							0.1
Crangon alba	Arthropoda			0.2				
Cumacea	Arthropoda		0.2	0.2				
Cuspidaria parapodema	Mollusca						0.8	
Cyclaspis nubila	Arthropoda		0.7	0.3				
Cyclocardia ventricosa	Mollusca			0.3	0.2		0.2	
Cylichna diegensis	Mollusca			2.7		0.3	0.2	2.7
Decamastus gracilis	Annelida					2.0	1.8	0.1
Deflexilodes norvegicus	Arthropoda						0.8	0.4
Dendraster terminalis	Echinodermata		1.7					
Dendrochirotida	Echinodermata						0.2	
Dentalium neohexagonum	Mollusca		0.5					
Dentalium vallicolens	Mollusca			0.2				
Diastylis californica	Arthropoda							0.1
Diastylis crenellata	Arthropoda						0.2	0.2
Diastylis santamariensis	Arthropoda			0.2				
Diastylopsis tenuis	Arthropoda		11.7	0.5				
Diopatra sp	Annelida			4.8				0.5
Diopatra splendidissima	Annelida		0.5					
Diopatra tridentata	Annelida			0.5				0.1
Dipolydora socialis	Annelida		0.5	0.5			0.5	1.1
Dorvillea (*Schistomeringos*) sp	Annelida	7.0						
Dougaloplus amphacanthus	Echinodermata		0.3				1.7	
Dougaloplus sp	Echinodermata					0.3		
Dougaloplus sp A	Echinodermata					1.0		0.5
Drilonereis falcata	Annelida			0.2		0.3	0.2	0.2
Drilonereis filum	Annelida						0.2	

Appendix H.2 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Drilonereis sp	Annelida			0.3		0.3	0.8	
Echinoidea	Echinodermata		0.5					0.1
Eclysippe trilobata	Annelida				1.6		0.3	0.7
Edotia sublittoralis	Arthropoda	3.0	0.7	0.3				
Edwardsia profunda	Cnidaria				0.2			
Edwardsia sp G	Cnidaria			1.0				
Edwardsiidae	Cnidaria					0.3		
Elaeocyma empyrosia	Mollusca							0.1
Ennucula tenuis	Mollusca				2.4		1.7	6.2
Enopla	Nemertea	3.0	0.2	0.2				
Ensis myrae	Mollusca			0.2				
Enteropneusta	Chordata			0.2				0.1
Epitonium (*Nitidiscala*) sp	Mollusca		0.2					
Epitonium bellastriatum	Mollusca			0.2				
Eranno bicirrata	Annelida							0.1
Eranno lagunae	Annelida						0.3	
Eranno sp	Annelida							0.2
Euchone arenae	Annelida			0.3		0.3		0.1
Euchone hancocki	Annelida					3.3		
Euchone incolor	Annelida					0.7		0.5
Euchone sp	Annelida						0.3	
Euchone sp A	Annelida					0.7		0.2
Euclymeninae	Annelida			1.5			1.2	0.6
Euclymeninae sp A	Annelida			11.2			0.5	3.5
Eulalia californiensis	Annelida							0.2
Eulalia levicornuta complex	Annelida	1.0					0.2	
Eulimidae	Mollusca			0.2				
Eulimidae sp SD1	Mollusca				0.4			
Eunice americana	Annelida			0.3			0.2	0.1
Euphilomedes carcharodonta	Arthropoda		2.2	5.0		0.7		1.2
Euphilomedes producta	Arthropoda					0.7		1.4
Eurydice caudata	Arthropoda	7.0		1.3				
Eusyllinae	Annelida	1.0						
Eusyllis sp SD2	Annelida	1.0		1.5				
Eusyllis transecta	Annelida		0.3	0.2				
Exogone acutipalpa	Annelida					0.3		
Exogone lourei	Annelida		1.7	2.0		3.7		
Exogone molesta	Annelida		2.0					
Eyakia robusta	Arthropoda					0.3	0.5	0.6
Falcidens longus	Mollusca							0.3
Fauveliopsis glabra	Annelida				1.2			
Fauveliopsis sp SD1	Annelida				0.4	21.7		0.2
Foxiphalus cognatus	Arthropoda					0.3		
Foxiphalus golfensis	Arthropoda			1.0				
Foxiphalus obtusidens	Arthropoda		0.2	0.5		1.7		
Foxiphalus similis	Arthropoda							0.7
Gadila aberrans	Mollusca		0.3	3.2				1.2
Gadila tolmiei	Mollusca				2.8		0.2	
Gammaropsis martesia	Arthropoda		0.2					

Appendix H.2 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Gammaropsis ociosa	Arthropoda		0.2					
Gammaropsis thompsoni	Arthropoda		0.7					
Gibberosus myersi	Arthropoda		7.2	0.2				
Glossaulax reclusianus	Mollusca							0.1
Glycera americana	Annelida		0.2	0.2		0.3	0.3	0.1
Glycera macrobranchia	Annelida		1.0	0.2				
Glycera nana	Annelida				0.6	1.7	1.8	1.9
Glycera oxycephala	Annelida		0.7	2.0		0.7		
Glycinde armigera	Annelida		2.7	1.2	1.0	0.3	0.8	0.8
Glyphocuma sp A	Arthropoda					0.3		
Gnathiidae	Arthropoda					0.3		
Goniada brunnea	Annelida						0.5	0.1
Goniada littorea	Annelida		4.2					
Goniada maculata	Annelida			1.0		1.7	0.7	0.8
Gymnonereis crosslandi	Annelida							0.1
Halicoides synopiae	Arthropoda		0.2					0.7
Haliophasma geminatum	Arthropoda			0.5		0.3		
Halistylus pupoideus	Mollusca	1.0						
Halosydna johnsoni	Annelida			0.2				
Hartmanodes hartmanae	Arthropoda		0.2	0.2		0.7		0.2
Hemilamprops californicus	Arthropoda			1.7				0.2
Hesionura coineaui difficilis	Annelida	30.0		0.2				
Heteronemertea sp SD2	Nemertea					1.0		
Heterophoxus ellisi	Arthropoda				0.4		1.3	
Heterophoxus oculatus	Arthropoda						0.2	0.9
Heterophoxus sp	Arthropoda						0.2	
Heterospio catalinensis	Annelida			0.2		0.3		
Hinea insculpta	Mollusca					1.3	0.2	
Hippomedon sp A	Arthropoda							0.2
Hoplonemertea sp A	Nemertea			0.3		0.3		
Hoplonemertea sp SD3	Nemertea							0.1
Hourstonius vilordes	Arthropoda	1.0						
Huxleyia munita	Mollusca					3.7		0.1
Hyalinoecia juvenalis	Annelida							0.1
Jasmineira sp B	Annelida			0.2		0.3	0.3	
Kurtziella plumbea	Mollusca			0.3				
Kurtzina beta	Mollusca							0.6
Lamprops quadriplicatus	Arthropoda		2.5					
Lanassa venusta venusta	Annelida			2.5		0.7	0.7	0.2
Laonice cirrata	Annelida			1.2			0.5	0.4
Laonice nuchala	Annelida					0.3	0.5	
Laticorophium baconi	Arthropoda			0.2				
Leitoscoloplos pugettensis	Annelida		0.3	0.3				
Leitoscoloplos sp A	Annelida				1.2			
Lepidasthenia longicirrata	Annelida						0.2	
Leptochelia dubia	Arthropoda			0.3		2.7	0.7	1.2
Leptopecten latiauratus	Mollusca		1.3	0.7				
Leptoplanidae	Platyhelminthes					0.3		
Leptostylis abditis	Arthropoda							0.2

Appendix H.2 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Leptosynapta sp	Echinodermata		0.2	0.2			0.2	0.2
Leuroleberis sharpei	Arthropoda			0.3				
Levinsenia gracilis	Annelida						0.7	0.5
Levinsenia sp B	Annelida						0.8	0.2
Limatula saturna	Mollusca							0.1
Limifossor fratula	Mollusca				1.0			
Limnactiniidae sp A	Cnidaria						0.2	
Lineidae	Nemertea		0.8	1.0	0.2	0.3	0.2	0.2
Lineus bilineatus	Nemertea							0.2
Lirobarleeia kelseyi	Mollusca			0.2				
Lirobittium larum	Mollusca			0.3		1.0		0.2
Listriella albina	Arthropoda						0.2	
Listriella diffusa	Arthropoda	1.0						
Listriella eriopisa	Arthropoda							0.1
Listriella goleta	Arthropoda							0.3
Listriella melanica	Arthropoda		0.2					
Listriolobus pelodes	Echiura							0.1
Lucinisca nuttalli	Mollusca			0.3				
Lucinoma annulatum	Mollusca						1.3	0.7
Lumbrineridae group III	Annelida		0.2				0.2	0.1
Lumbrinerides platypygos	Annelida	40.0		1.0				
Lumbrineris cruzensis	Annelida				0.6		2.5	3.3
Lumbrineris latreilli	Annelida			1.8				
Lumbrineris lingulata	Annelida	1.0	0.2	1.2				
Lumbrineris sp group I	Annelida		0.2			0.3	2.5	2.2
Lumbrineris sp group II	Annelida		0.2					0.2
Lyonsia californica	Mollusca			2.0				0.1
Lyonsiidae	Mollusca		0.3					0.1
Lysippe sp A	Annelida			0.2		1.3	2.5	0.4
Lysippe sp B	Annelida						0.7	1.2
Macoma carlottensis	Mollusca				9.6		1.0	
Macoma sp	Mollusca		0.5				2.0	0.1
Macoma yoldiformis	Mollusca			2.5				
Macrochaeta sp A	Annelida	2.0						
Mactridae	Mollusca		0.3					
Mactromeris hemphilli	Mollusca		8.2					
Magelona sacculata	Annelida						0.2	
Magelona sp B	Annelida					1.0	0.8	
Maldane sarsi	Annelida				4.8		4.2	2.8
Maldanidae	Annelida		0.2	2.5	5.6	0.3	1.2	1.2
Maldaninae	Annelida		0.2	0.2				
Malmgreniella macginitiei	Annelida			0.5				
Malmgreniella sanpedroensis	Annelida					0.7	0.3	0.1
Malmgreniella scriptoria	Annelida				0.2			
Malmgreniella sp A	Annelida			0.5	0.2		0.2	1.2
Mayerella banksia	Arthropoda					2.0		0.8
Mediomastus acutus	Annelida		0.5	0.2				
Mediomastus sp	Annelida	1.0	3.7	8.5	0.6	5.3	5.7	2.2
Megalomma pigmentum	Annelida		0.3	0.7				

Appendix H.2 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Megalomma splendida	Annelida							0.1
Megaluropidae sp A	Arthropoda			0.2				
Megasurcula carpenteriana	Mollusca							0.1
Melanella rosa	Mollusca		0.2					
Melinna heterodonta	Annelida					0.7	3.0	
Melinna oculata	Annelida			1.0				
Melitidae	Arthropoda	1.0						
Mesochaetopterus sp	Annelida						0.2	
Mesolamprops bispinosus	Arthropoda			0.3				0.4
Metaphoxus frequens	Arthropoda						0.2	
Metasychis disparidentatus	Annelida		0.2	0.2			0.2	0.3
Metatiron tropakis	Arthropoda					0.3		
Metharpinia jonesi	Arthropoda		0.2					
Micranellum crebricinctum	Mollusca			0.2		17.3		
Microphthalmus sp	Annelida	1.0						
Micrura alaskensis	Nemertea			0.3				0.1
Modiolus sp	Mollusca		1.3					
Molgula pugetiensis	Chordata			1.5				0.2
Molgula sp	Chordata			0.8				0.2
Monoculodes emarginatus	Arthropoda					1.3	0.2	0.5
Monticellina cryptica	Annelida		7.3	0.3		2.0	1.5	0.8
Monticellina siblina	Annelida		0.2	15.8		8.0	4.0	0.5
Monticellina sp	Annelida		0.7			1.0	0.7	
Monticellina tesselata	Annelida			0.2			0.7	
Mooreonuphis exigua	Annelida					0.3		
Mooreonuphis nebulosa	Annelida			12.8				0.8
Mooreonuphis segmentispadix	Annelida					6.0		
Mooreonuphis sp	Annelida	4.0		7.0		0.7		
Mooreonuphis sp SD1	Annelida			9.7		0.3		
Mooresamytha bioculata	Annelida			0.3				
Myriochele gracilis	Annelida					0.3	0.7	0.5
Myriochele striolata	Annelida			0.5		2.7		
Myriowenia californiensis	Annelida							0.2
Naineris uncinata	Annelida					1.3		
Neaeromya rugifera	Mollusca							0.1
Neastacilla californica	Arthropoda			0.2				
Nellobia eusoma	Echiura				0.2			
Nematoda	Nematoda	23.0	0.2	0.8		0.3		
Neosabellaria cementarium	Annelida			0.7				
Nephasoma diaphanes	Sipuncula					0.3		0.1
Nephtys caecoides	Annelida		0.3	0.2		0.3	0.3	0.2
Nephtys cornuta	Annelida				0.2		0.2	
Nephtys ferruginea	Annelida					0.7	1.0	0.8
Nephtys sp SD2	Annelida			0.2				
Nereiphylla sp 2	Annelida			0.2		0.3		
Nereis latescens	Annelida		0.8					
Nereis sp A	Annelida		0.2	0.8				0.3
Nicippe tumida	Arthropoda						0.3	0.5
Ninoe tridentata	Annelida						0.2	

Appendix H.2 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Nothria occidentalis	Annelida							0.2
Notocirrus californiensis	Annelida						0.2	
Notomastus latericeus	Annelida			1.3		0.3		
Notomastus sp	Annelida			0.2	0.2			
Notomastus sp A	Annelida			0.3	0.4	1.7	1.3	0.4
Notoproctus pacificus	Annelida							1.0
Nuculana conceptionis	Mollusca				11.0			
Nuculana hamata	Mollusca							0.2
Nuculana leonina	Mollusca				0.4			
Nuculana penderi	Mollusca		0.7					
Nuculana sp A	Mollusca						2.3	2.1
Nuculana taphria	Mollusca		0.2	4.2				0.2
Odontosyllis phosphorea	Annelida			0.2				
Odostomia sp	Mollusca		0.3					0.2
Oerstedia dorsalis	Nemertea					1.0		
Okenia sp A	Mollusca			0.2				
Oligochaeta	Annelida	15.0						
Onuphidae	Annelida		3.8	0.7			0.2	
Onuphis elegans	Annelida		0.2					
Onuphis eremita parva	Annelida			0.2				
Onuphis iridescens	Annelida				0.4		0.5	
Onuphis sp	Annelida		1.8					
Onuphis sp A	Annelida		7.3	3.0			0.7	0.2
Ophelia pulchella	Annelida	4.0		0.2				
Ophelina acuminata	Annelida				0.2			
Ophelina sp SD1	Annelida					0.7		
Ophiodermella inermis	Mollusca		0.8					0.1
Ophiura luetkenii	Echinodermata		0.2			0.3		0.2
Ophiuroconis bispinosa	Echinodermata			5.3				1.7
Ophiuroidea	Echinodermata				0.4			
Opisthodonta sp SD1	Annelida	2.0						
Orchomenella pacifica	Arthropoda					1.7		
Owenia collaris	Annelida		118.5					0.1
Oxyurostylis pacifica	Arthropoda			0.2				
Pacifacanthomysis nephrophthalma	Arthropoda							0.1
Palaeonemertea	Nemertea			0.2				0.1
Pandora bilirata	Mollusca			0.2	0.2		0.2	0.4
Paradiopatra parva	Annelida		0.2			0.3	4.2	1.7
Parandalia fauveli	Annelida							0.1
Paranemertes californica	Nemertea			0.3				
Paraonidae	Annelida			0.2				0.2
Paraprionospio alata	Annelida			0.3	0.8	0.7	1.7	0.5
Pardaliscella symmetrica	Arthropoda						0.3	
Parougia caeca	Annelida			0.2				
Parvilucina tenuisculpta	Mollusca		0.3	0.3	0.6	5.0	4.8	0.8
Pectinaria californiensis	Annelida		0.3		0.2		1.0	0.5
Pentamera populifera	Echinodermata						0.2	0.1
Pentamera pseudopopulifera	Echinodermata			0.2				0.1
Pentamera sp	Echinodermata			0.7				

Appendix H.2 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Periploma discus	Mollusca			0.3				
Petaloclymene pacifica	Annelida			0.7	0.2		2.7	2.3
Petaloproctus neoborealis	Annelida							0.2
Phascolion sp A	Sipuncula		0.3	0.2			0.7	1.2
Pherusa negligens	Annelida						0.2	
Pherusa neopapillata	Annelida			0.8			0.2	0.2
Pherusa sp SD2	Annelida				0.4			
Philine auriformis	Mollusca			0.2				
Phisidia sanctaemariae	Annelida			0.3			0.7	1.2
Pholoe glabra	Annelida					1.3	0.3	3.4
Pholoides asperus	Annelida							0.1
Phoronis sp	Annelida							0.5
Phoronis sp SD1	Annelida		0.3			0.3		
Phoronopsis sp	Annelida		0.5					
Photis bifurcata	Arthropoda						0.3	0.1
Photis brevipes	Arthropoda		3.5	0.2				
Photis californica	Arthropoda							0.5
Photis lacia	Arthropoda					5.0		0.2
Photis macinerneyi	Arthropoda		6.7					
Photis sp	Arthropoda		1.3	0.2		0.7		0.2
Photis sp C	Arthropoda							0.2
Photis sp OC1	Arthropoda		0.2	0.7				
Phoxocephalidae	Arthropoda			0.2			0.2	
Phyllochaetopterus limicolus	Annelida				0.2		1.5	
Phyllodoce groenlandica	Annelida			0.8			0.7	0.2
Phyllodoce hartmanae	Annelida		0.3	1.0			0.2	0.4
Phyllodoce longipes	Annelida			0.3				0.2
Phyllodoce pettiboneae	Annelida			0.2				0.2
Pilargis berkeleyae	Annelida							0.1
Pinnixa longipes	Arthropoda			0.3				
Pinnixa occidentalis complex	Arthropoda				0.4			1.2
Pinnixa sp	Arthropoda			0.3				0.2
Pionosyllis sp SD2	Annelida	2.0		0.5				
Piromis sp A	Annelida						0.2	0.2
Pisione sp	Annelida	38.0						
Pista estevanica	Annelida			0.3		1.0	0.8	0.4
Pista moorei	Annelida						0.2	
Pista sp	Annelida			0.3		0.7		
Pista wui	Annelida			0.3			0.7	0.2
Plakosyllis sp	Annelida	1.0						
Platynereis bicanaliculata	Annelida		0.3	0.2				
Podarkeopsis glabrus	Annelida							0.5
Podarkeopsis perkinsi	Annelida				0.2			
Poecilochaetus johnsoni	Annelida			0.2				
Polycirrus californicus	Annelida					0.3		
Polycirrus sp	Annelida			1.5	0.2	0.7	1.0	0.6
Polycirrus sp A	Annelida			3.3		3.7	1.5	2.1
Polycirrus sp I	Annelida			0.5				
Polycirrus sp OC1	Annelida							0.1

Appendix H.2 *continued*

Species/Taxa	Phyla	Cluster Group A	B	C	D	E	F	G
Polycirrus sp SD1	Annelida							0.2
Polycirrus sp SD3	Annelida					0.3		0.1
Polydora cirrosa	Annelida		12.2	0.2				
Polyschides quadrifissatus	Mollusca		0.2	1.5			0.3	0.4
Praxillella pacifica	Annelida			2.5			2.2	1.8
Prionospio (*Minuspio*) *lighti*	Annelida			0.2	0.2	0.3	0.3	0.5
Prionospio (*Prionospio*) *dubia*	Annelida					2.0	1.7	2.8
Prionospio (*Prionospio*) *ehlersi*	Annelida				0.6			
Prionospio (*Prionospio*) *jubata*	Annelida			0.7	0.2	3.3	1.2	2.3
Procampylaspis caenosa	Arthropoda					0.7		0.2
Proclea sp A	Annelida							1.8
Proneomysis wailesi	Arthropoda	1.0						
Protodorvillea gracilis	Annelida	19.0		0.8		0.3		
Protomedeia articulata complex	Arthropoda					0.3		0.3
Protomystides sp SD2	Annelida							0.1
Prototrygaeus jordanae	Arthropoda			0.2				
Pseudopotamilla sp	Annelida		0.3					
Questa caudicirra	Annelida	4.0						
Rhabdus rectius	Mollusca				0.4		0.5	
Rhachotropis sp A	Arthropoda							0.6
Rhepoxynius abronius	Arthropoda		8.5	0.7				
Rhepoxynius bicuspidatus	Arthropoda						1.0	3.1
Rhepoxynius fatigans	Arthropoda			0.2				
Rhepoxynius heterocuspidatus	Arthropoda			1.3				
Rhepoxynius menziesi	Arthropoda		1.8	1.5				0.2
Rhepoxynius sp A	Arthropoda		0.2					
Rhepoxynius stenodes	Arthropoda		0.7	1.0				
Rhepoxynius variatus	Arthropoda			1.5				
Rhodine bitorquata	Annelida						0.5	1.1
Rhynchospio arenincola	Annelida		0.3					
Rictaxis punctocaelatus	Mollusca			1.7		1.0	0.2	
Rochefortia coani	Mollusca							0.1
Rochefortia tumida	Mollusca		0.2	1.2			0.2	3.5
Sabellaria gracilis	Annelida		0.3					0.1
Sabellidae	Annelida					0.3		
Sabellides manriquei	Annelida			0.2				0.1
Saccoglossus sp	Chordata			0.2				
Samytha californiensis	Annelida			0.2	0.2		0.3	0.3
Saxicavella pacifica	Mollusca				2.4			
Scalibregma californicum	Annelida							0.5
Scaphopoda	Mollusca	1.0		0.2	0.2	0.3	0.2	
Scaphopoda sp SD1	Mollusca				1.8			
Schistocomus sp	Annelida		0.2					
Schistocomus sp A	Annelida		0.3					
Scolanthus sp A	Cnidaria							0.1
Scoletoma tetraura complex	Annelida		7.5	0.5	0.6		1.7	0.4
Scoloplos acmeceps	Annelida					0.3		
Scoloplos armiger complex	Annelida		0.8	1.0		0.7	0.3	1.3
Scoloura phillipsi	Arthropoda					0.7		

Appendix H.2 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Sigalion spinosus	Annelida		0.8	2.2				0.3
Sigalionidae	Annelida	1.0						
Sige sp A	Annelida		0.2	0.3			0.3	
Siliqua lucida	Mollusca		3.5					
Simomactra falcata	Mollusca	1.0	0.3					
Siphonolabrum californiensis	Arthropoda					0.3		0.2
Sipuncula	Sipuncula	1.0						
Skenea coronadoensis	Mollusca		0.8					
Solamen columbianum	Mollusca			0.3	0.4			0.2
Solariella peramabilis	Mollusca	1.0				1.0		
Solemya pervernicosa	Mollusca							0.2
Solen sicarius	Mollusca			0.3				
Spatangoida	Echinodermata				0.2			
Spatangus californicus	Echinodermata					0.3		
Sphaeromatidae	Arthropoda					0.3		
Sphaerosyllis californiensis	Annelida	8.0						
Spio filicornis	Annelida			0.2				0.3
Spio maculata	Annelida	60.0		0.7				0.1
Spiochaetopterus costarum complex	Annelida		0.5	0.2			1.0	0.2
Spiophanes berkeleyorum	Annelida		0.2	5.2			0.8	6.8
Spiophanes duplex	Annelida		8.8	4.0			0.3	2.0
Spiophanes fimbriata	Annelida				0.4		0.2	
Spiophanes kimballi	Annelida				1.0		4.2	0.1
Spiophanes norrisi	Annelida	2.0	11.5	50.5		0.3		0.2
Stenothoe frecanda	Arthropoda							0.5
Stenothoides bicoma	Arthropoda							0.5
Stereobalanus sp	Chordata			0.2			0.2	3.2
Sternaspis fossor	Annelida						2.5	2.5
Sthenelais tertiaglabra	Annelida			0.5		0.3	1.5	0.5
Sthenelais verruculosa	Annelida			0.2				
Sthenelanella uniformis	Annelida					0.3		0.7
Streblosoma crassibranchia	Annelida							0.4
Streblosoma sp	Annelida			1.7			0.2	0.2
Streblosoma sp B	Annelida			2.5				0.2
Streblosoma sp SF1	Annelida			1.2				
Stylochoplana sp HYP2	Platyhelminthes							0.1
Syllides mikeli	Annelida					0.7		
Synidotea magnifica	Arthropoda			0.2				
Tanaella propinquus	Arthropoda						0.5	0.2
Tanaidacea	Arthropoda					0.3		
Tanaopsis cadieni	Arthropoda					1.0	0.2	0.4
Tellina cadieni	Mollusca						0.5	0.2
Tellina carpenteri	Mollusca				0.4	19.7	8.7	0.6
Tellina modesta	Mollusca		3.2	4.0				
Tellina nuculoides	Mollusca		0.2					
Tellinidae	Mollusca			0.3				
Tenonia priops	Annelida			0.2				
Terebellidae	Annelida							0.2
Terebellides californica	Annelida						11.5	2.6

Appendix H.2 *continued*

Species/Taxa	Phyla	A	B	C	D	E	F	G
		Cluster Group						
Terebellides reishi	Annelida							0.1
Terebellides sp	Annelida						0.2	0.2
Terebellides sp Type D	Annelida							0.1
Tetrastemma nigrifrons	Nemertea		0.2					
Thorlaksonius platypus	Arthropoda		0.2					
Thracia sp	Mollusca							0.1
Thracia trapezoides	Mollusca							0.2
Thraciidae	Mollusca			0.2				
Thyasira flexuosa	Mollusca				0.2		0.3	0.9
Thyasiridae sp LA1	Mollusca					0.3		
Thysanocardia nigra	Sipuncula		0.5	1.0				0.3
Tiburonella viscana	Arthropoda	4.0						
Tiron biocellata	Arthropoda		0.3	0.5				
Travisia brevis	Annelida							3.5
Travisia pupa	Annelida				0.4		0.2	
Trigonulina novemcostatus	Mollusca					0.7		
Tritella pilimana	Arthropoda		0.8					0.4
Trypanosyllis sp	Annelida	4.0						
Tubulanidae	Nemertea							0.1
Tubulanus cingulatus	Nemertea							0.1
Tubulanus polymorphus	Nemertea		0.7	1.7			0.2	0.3
Tubulanus sp A	Nemertea			0.2				0.2
Turbonilla sp A	Mollusca		1.5	0.2				
Turbonilla sp SD1	Mollusca		0.2	0.7				0.2
Turbonilla sp SD2	Mollusca			0.2				0.2
Turbonilla sp SD5	Mollusca							0.2
Turbonilla sp SD6	Mollusca		0.2					
Turbonilla sp SD7	Mollusca							0.1
Typhlotanais williamsi	Arthropoda					1.3		
Typosyllis farallonensis	Annelida		0.8					
Typosyllis heterochaeta	Annelida			0.2			0.7	0.1
Typosyllis sp SD1	Annelida			0.8				
Typosyllis sp SD2	Annelida	1.0		1.7				
Urothoe elegans complex	Arthropoda					3.3		
Venerinae	Mollusca		0.2					
Virgularia agassizii	Cnidaria						0.2	
Virgularia sp	Cnidaria							0.2
Virgulariidae	Cnidaria							0.1
Vitreolina yod	Mollusca	1.0						
Volvulella californica	Mollusca							0.1
Volvulella cylindrica	Mollusca			1.0				
Volvulella panamica	Mollusca						0.7	1.3
Westwoodilla tone	Arthropoda			0.3		1.3	0.3	0.3
Xenoleberis californica	Arthropoda					0.3		
Yoldia cooperii	Mollusca		0.2					
Yoldiella nana	Mollusca				1.8			
Zaolutus actius	Cnidaria		18.5					
Zygeupolia rubens	Nemertea						0.8	0.2

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